DEVELOPMENT OF A HYDROLOGIC COMPUTER MODEL FOR A TROPICAL RAINFOREST BASIN WITH EMPHASIS ON FRICTION FACTORS

By

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This dissertation is dedicated to the Lord God Almighty, His Son Jesus, The Holy Spirit and my family:

Emilienne Koné
Ferima Koné
N'Guessan Amoin
Vamara Koné
Adama Koné
Sibiry Koné
The late Fatou Koné
Awa Koné
Sita Koné
Salif Koné
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Bibata Koné
Karim Ouattara
Brahima Koné
Kadi Koné
Salomon Koné

my cousins, my uncles, my aunts, my nephews and nieces, and all my family in-laws.

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Abstract of Dissertation Presented to the Graduate School
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The hydrology of tropical zones is not as well documented as that of temperate regions. With the deforestation of the tropical rainforest, environmental changes--such as those causing global warming--are disrupting the normal hydrologic cycle of tropical lands. These changes need to be monitored if one wants to maintain the hydrological balance of the tropical areas.

In the research conducted here, a hydrologic computer model called TROPICS was developed in the FORTRAN 77 Language by synthesizing some of current knowledge of the hydrology of the Tropics, to forecast an hourly hydrograph at the outlet of a tropical rainforest basin using hourly rainfall data over one week. To achieve the above objective, hydrologic variables such as evapotranspiration

(ET), interception, infiltration, groundwater flow, channel flow, canopy density--a factor influencing runoff in forested zones--and the resistance to flow introduced by the presence of large tree trunks were investigated. Equations used to simulate the parameters described above were chosen or developed according to their efficiency in predicting those variables in tropical zones.

Key variables, such as the canopy density, the overland flow, channel and groundwater flows, were given particular consideration. A new equation was developed to calculate the canopy density. The overland flow was predicted by dividing the basin into square elements of various size with a maximum of two channel segments crossing each element. The flow was then routed from element to element down to the watershed outlet using a combination of the continuity equation for mass conservation and the Darcy-Weisbach equation for estimates of friction losses. Groundwater flow was accounted for, by dividing the soil profile into an upper unsaturated zone and a lower saturated zone according to the water table position. The study of moisture changes was done by making a moisture balance in those two zones.

Once the model development was accomplished, TROPICS was used to predict the hydrologic variables, described earlier, on a tropical rainforest basin in Puerto Rico. Good values of ET, as well as infiltration, runoff excess and canopy density were obtained. The canopy density, values ranged between 23% and 100% for the different elements of the watershed. Those values represent real life canopy density values of the rainforest. TROPICS predicted flow values using hourly rainfall data with a correlation coefficient R2 equals 0.94. In general, the hydrologic variables predicted with TROPICS appear to be satisfactory.

CHAPTER 1
INTRODUCTION

1.1 Hydrology of the Tropical Rain Forest

The tropical regions of the world are bound by two parallels of latitude 23°27' north and south of the equator (Fig. 1). These zones represent approximately 40% of the earth's surface. They are found in Africa, Asia, Australia, South, North and Central America, and Indonesia. The sun is overhead in the tropics twice a year. Therefore, its influence is more predominant on climatic and temperature changes than elsewhere in the world (Balek, 1977). These changes also affect the vegetation patterns. Savannahs, rain forests, and deserts are closely related to the climatologic factors prevailing in the tropical zones. The parameters affecting the hydrology of the tropics have been underlined by Quinones et al. (1985); wind patterns, temperature, humidity, insolation, physiography, geology, precipitation, and drainage are the major factors that he mentioned. The manifestations of the factors are trade winds, monsoons, tropical storms, hurricanes, high humidity, high temperatures, floods, high evapotranspiration rates, landslides, and erosion. The above factors clearly show that difference between tropical and temperate

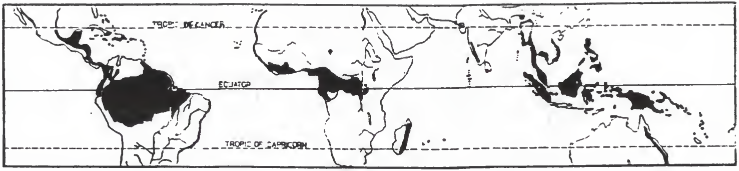


Figure 1. Tropical rainforest zones of the world.
(Adapted from Hamilton and King, 1983)

zone hydrology. The absence of snow in the tropics is also a major difference compared to the temperate zones. The purpose of the research here is not to redemonstrate that hydrologic processes such as infiltration, storage, water release, etc. depend on complex interactions between topography, climate, vegetation and human activities (there are no intrinsic reasons why tropical regions should not respond to the laws of nature as do temperate zones (Hamilton et al., 1983)) but to show how those processes are different from those of temperate zones and how they can be linked together in a computer modeling of tropical rain forest hydrology. Modeling hydrologic processes in tropical rain forest areas is very important because the recent deforestation of tropical rain forests is introducing changes in the hydrologic cycle which need to be monitored if one wants to maintain the hydrological balance of the rain forest (Hamilton and King, 1983; Quinones et al., 1985). Maintaining the hydrologic balance is critical not only for the local populations but for the whole world, because of the importance of the rain forest in transforming the CO_2 into O_2 and carbon compounds by the photosynthesis process. To assume a proper protection of the rain forest, the University of Humid Tropics (UNITROP) was created at the Conference on Global Biomass Burning held on March 23, 1990 in Williamsburg, Virginia. The headquarters for UNITROP is in Manqus, Brazil. The objective of UNITROP is to do research to promote, organize and fund researchers to lead to an integrated understanding of the tropical forest environment and its transformation and also to preserve the Amazon Forest. The modeling approach undertaken here shares the same concerns as the founder of UNITROP. It also aims at synthesizing current knowledge in rain forest hydrology in order to build a computer model called TROPICS, which forecasts the outflow hydrograph of a rain forest watershed for a better understanding of the water cycle in the rain forest zones.

1.2 Objectives of the Research

As stated above, the objective of the research reported in this dissertation is to develop a computer model to generate a flow hydrograph for a rainforest basin. The objective will be accomplished through the following steps:

a) Assess the characteristics of the tropical rain forest hydrology.

b) Establish equations to model hydrological processes such as overland flow (study of change of friction factors) infiltration, ET, channel flow, etc.

c) Build the model by linking the different processes together to obtain the outflow hydrograph.

d) Apply the developed model to tropical rainforest watershed to verify or test the model.

The model in this its first version does not handle sediment, transport, erosion and water quality. Those components will be added later. Once the model is built the changes can be monitored by varying factors in the model to find out whether the model is sensitive to changes in those factors. For example, the changes in forest density create gaps, which in turn will favor erosion by an increase in water runoff volume and flow induced surface shear stresses.

CHAPTER 2
LITERATURE REVIEW

2.1 The Tropical Rain Forest Climate

2.1.1 Generalities

The equatorial position of the tropical forest ensures that more solar radiation strikes it than strikes other forests outside the tropics. There is also no winter period with reduced day length. Nevertheless, the tropical climate in general is not uniform. It varies widely according to the movement of continental air masses, air flow, and sea currents (Mabberly, 1983; Balek, 1977). These different variations of air masses give a variation of precipitation patterns, relative humidity, temperatures, winds, and vulnerability to violent storms. The above patterns affect the forest vegetation distribution. The ITCZ (Intertropical Convergence Zone) is a key factor in determining tropical climates. The ITCZ can be defined as follows: following the overhead position of the sun, the zone of greatest heat shift from the southern hemisphere in January to the northern hemisphere in July followed by a pressure trough which lags about a month (Balek, 1977). The front between the warm and dry stable air and the moist air is the ITCZ.

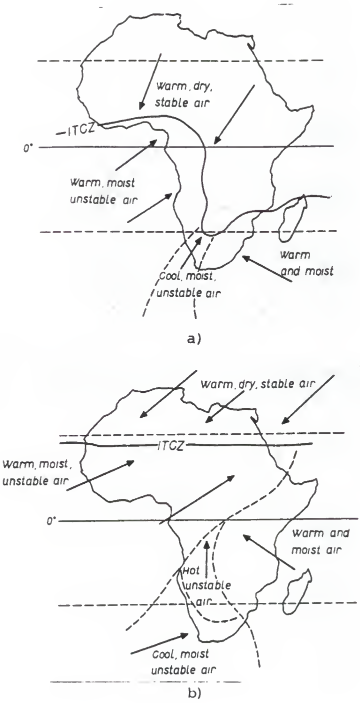


Figure 2. Position of the ITCZ a) January, b) July. (Adapted from Balek, 1977.)

Its position (Fig. 2) determines the climate of most of the tropical zones and the forest types existing in the tropics.

2.1.2 Temperatures

The annual mean temperature is about 27°C. The highest monthly values lie between 24-28°C. The maximum rarely exceeds 38°C and the minimum is rarely below 20°C. Generally the soil temperature does not exceed 30°C in closed forests, but can reach up to 50°C in gaps (open areas in the forest). The day length is about twelve hours and three quarters. The total radiation reaching the soil is approximately 2 to 3% of the total incoming radiation.

2.2 Precipitation

Precipitation is obtained by the lifting and cooling of large masses of air, and the falling of the water formed in drops. According to the precipitation amount the tropical climate can be classified in five major zones. Only the first three of these zones are closely related to tropical forest conditions.

1) The rainy tropical zones (tropical South America (Amazon area), Malaysia, the Congo basin (Africa)) have an average precipitation of about 2500 mm/year. In some specific zones it can reach up to 4000 mm/year (Nortcliff and Thornes, 1981). 2) The monsoon tropical zones (India and Burma) have an average precipitation of 2000 mm/year but with marked seasonal variations. 3) The wet and dry

tropical zones (East and West Africa) have a precipitation which varies between 800 and 3200 mm/year (Balek, 1977). 4) The tropical semi-arid zones (savannah and arbustive savannah regions of Africa and India) have an average rainfall of about 500 mm/year. 5) The tropical arid zones (arid region of North Africa) have precipitations of less than 500 mm/year.

In addition to the different types of climatic zones there are diverse forms of storms in tropical zones. They are generally referred to as cyclones, hurricanes, tornadoes, etc. These storms are mostly convective with a high rainfall intensity and result from the heating of the soil surface and forest canopy. They can variably be of short or long durations. Trewartha (1943) gives the following description of tropical cyclones:

a) The isobars are more symmetrical and nearly circular.

b) Pressure gradients are steeper and winds are stronger (sometimes they are over 120 km/hr).

c) Rains tend to be torrential and more evenly distributed toward the center.

d) They are numerous during the warm and cold seasons.

e) They have no anticyclonic companion.

Precipitation as emphasized by Mabberly (1983) is the major moisture source in the tropical forest zones. Dew and fog are the other sources. Mabberly also made the following distinction among the different processes by which precipitation is distributed over the forest zones on storm basis, monthly basis, and annual basis. Although the processes to be listed below will be reviewed later in greater details, here are Mabberly's distinctions:

a) Stemflow (flow from tree stems) varies from 0 to 2.65% on storm basis, 0.32 to 0.92% on monthly basis, and 0.64% on annual basis.

b) Throughfall (rainfall nonintercepted) varies from 0 to 99.1% on storm basis, 65.27% to 94.64% on monthly basis, and 77.56% on annual basis.

c) Interception (rainfall intercepted by forest canopy) varies from 0 to 100% on storm basis, 5.04% to 34.31% on monthly basis, and 21.8% on annual basis.

2.3 Vegetation

Importance of the Rain Forest Vegetation

At the present time tropical forest covers about 6% of the world surface and contains half of the earth total animal and plant species including 70 to 75% of all known anthropods (Mabberly, 1983). It covered approximately 16 million km^2 but this number dwindled down to 9-11 million km^2 in the seventies. In the mid-seventies the decrease in forest surface was about 11,000 km^2/year (Mabberly, 1983). This decrease percentage-wise could be subdivided as follows: 37% for Latin America, 41.6% for Asia, and 51.6%

for Africa. More recently in the eighties it has been reported that half of the existing forest is going at a rate of 11 to 40 ha/min. Many authors such as Pereira (1981), Hamilton and King (1983), Lal and Russel (1979), and Kunkle and Dye (1981) have sharply denounced the often negative ecosystem changes introduced by pronounced deforestation. But before an in-depth analysis in the following chapters of the effects of deforestation and other related problems, it seems adequate to define the term tropical forest for a better understanding of the effects mentioned above. As stated earlier, there are three major types of tropical forests: the tropical rainforest, the monsoon forest and the wet and dry tropical forest. The tropical rainforest is the one studied in this report.

a) The tropical rain forest: The term rain forest was originally introduced by the German researcher Schimper (1898). He defined rain forest as being <<evergreen, hydrophilous in character at least 30 m high rich in thick stem lines, in woody and herbaceous epiphytes>>. Later on, Myers (1980) changed the term tropical rain forest into tropical moist forest, which is defined as being <<evergreen, partly evergreen in areas, receiving not less than 100 mm of rainfall per month in any month for two out of three years, with mean temperatures of 24°C and frost free>>.

Although these definitions are clear and concise, it is very difficult to find a forest which can entirely fit the categories defined above. For this reason, the term rain forest has been generalized and applied to many other types of forests which are less evergreen with less mean annual rainfall.

b) The monsoon forest: This type of forest is generally leafless during the dry season especially toward its end. Although this type of forest has lines and herbaceous epiphytes, they are poor in woody epiphytes.

c) The wet and dry forest: It is also called mixed deciduous and dry evergreen forest. This type of forest is found in part of West Africa and Trinidad (Richards, 1952).

In addition to the above classification, Sasson and Fournier (1983) gave another definition of the tropical forest by classifying it according to climatic considerations based upon the annual moisture (humidity) existing in a given area. Their classification is as follows:

a) The hyper-humid climate forest: This type of forest comprises the Amazonian forest and the Queensland forest of Australia.

b) The very humid climate forest: It is the evergreen African and part of the South American forest and the semi-evergreen monsoon forest.

c) The humid climate forest: This type comprises the semi-deciduous African and Asian forests.

All the above types of forests, as underlined by the authors, receive more than 1500 mm of rainfall on the average per year. The rain forest studied in this project fits Sasson's classification better.

2.4 Geology and Soils

2.4.1 Geology

The tropical rainforest zones are humid regions with complex geological structures. Most of those structures are: the precambrian shields, the sedimentation basins, the fold mountain systems and volcanic rocks (Faniran and Jeje, 1983).

a) The precambrian shield: It comprises stable rocks or cratons and is to a great extent the nuclei of continents to which mountain systems of various ages have been "welded." As an example, most of the tropical African forest zones, except the depositional basins of West Africa, Central Africa and Kalahari regions, are composed of the precambrian rocks. These rocks have variable compositions but in general everybody agrees that their main elements are ferromagnesian rocks, mica schists, gneisses, quartzites, migmatites, granulites and schists (Haughton, 1963). Granites and metamorphosed lavas are also among precambrian rocks. These rocks have been reported to represent 50% of the South American rock systems. They are also found in India and in Malaysia.

b) The sedimentation basins: The oldest deposits comprise basal conglomerates, grits, lathyritic rubble which according to Cahen (1954) indicated a warm and humid phase. It was also noted that peripheral cratons called Inselbergs were uplifted giving a deformation of the sedimental basin. The tertiary uplift resulted in a wide spread erosion and sedimentation of basins. The Congo basin (central Africa) is an example of sedimentary rocks, they are composed of sands, sandstones, silt, silicated clays, clays and limestones. These rocks were deposited in the basin during different climatic regimes (Faniran and Jeje, 1983).

c) The fold mountain systems and volcanic rocks: The fold mountain system comprises the Andean Cordillera in South America, the Sierra Madre in Mexico, the Himalayan system in Thailand, and the Island mountains in Indonesia, New-Guinea and Australia. These mountains range in heights from 2,000 m to 8,000 m m.s.l. These regions sometimes have sedimentary rocks with granite intrusion (Rickard, 1975). The volcanic regions are composed of basalt, rhyolites, and dacites. These volcanic mountains are found in Indonesia, South America, and East Africa.

2.4.2 Soils

The rocks of precambrian shields, the sedimentary depositions, volcanic rocks, etc. influence the type of soils found in tropical forest zones. From the previous geology subsection, one can see that sands, sandstones, clays, schists, quartzites, silt, limestones, and volcanic soils are components of tropical soils. The soils originated from the decomposition or disintegration of rocks at the soil surface by the erosive power of winds, rainfall, etc. One process very important in the tropical rain forest regions is rock weathering. It has a key influence on soil composition. The definition of the term weathering is given by Ollier (1975) in the following words: "Weathering is the breakdown and alteration of materials near the soil surface to products that are more in equilibrium with newly imposed physico-chemical conditions" (pages 240-245). Rock weathering has produced one of the most common tropical soils, i.e. laterite.

Laterite, because of its presence in almost all tropical forest zones, has been given many names throughout the world. In India it is called iron clay; in Nigeria, ironstone; in Brazil, Canga; in French-speaking areas, 'cuirasse lateritique'. Laterite can be found in several forms: in combination with sandstones, gneisses or disintegrated granite or with shale (layered clay soils). The soil profiles in Figures 3 and 4 show the different

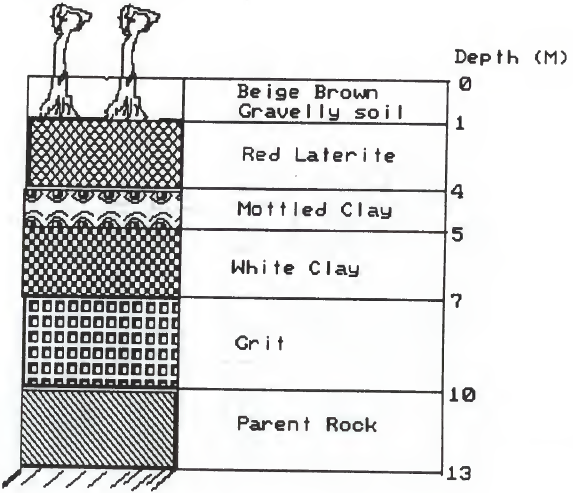


Figure 3. Laterite in sandstone.

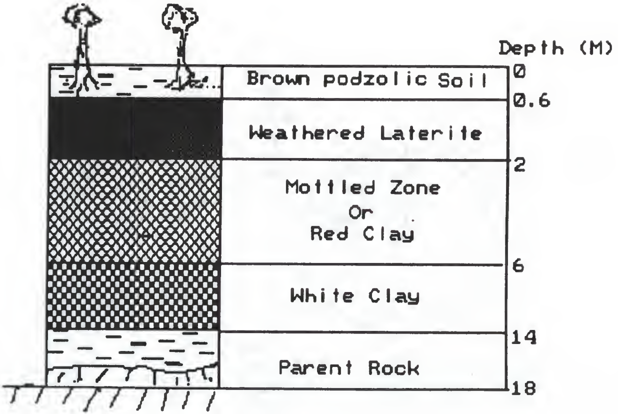


Figure 4. Laterite in shale.

types of laterite found in tropical zones. Water storage and flow in the soils depend on the permeability of the soils described above.

2.5 Hydrologic Processes in the Tropical Rain Forest

2.5.1 Interception

Interception is the amount of water held by the forest canopy during a rainfall event and never reaching ground level. It is determined by the amount and frequency of precipitations and the drying rate of the forest cover. Empirical studies have shown that interception varies widely with the forest type, density and stand (Lee, 1980).

Interception can greatly affect the distribution of rainfall by causing a nonuniform wetting of the forest soil. However, in major storms interception can be negligible compared to the total precipitation over the areas producing important channel and overland flows (Hewlett, 1982). Because of the above dependence of the interception process on rainfall amount and intensities, one can expect it to have different characteristics in the tropics compared to temperate zones. Interception in tropical zones is a well-documented topic. Many authors such as Zinke (1967), Balek (1977), and Jackson (1971) have thoroughly investigated that process.

Jackson (1971) related interception to various parameters as well as vegetation characteristics for a better estimation of the latter. His experiment was conducted in an East African forest zone. The interception process was modeled by diverse equations in order to find which method gives a better estimation of it. The first equation to be used was the following:

$$I = W + U*LN(D) + V*LN(R) + Z*LN(G) \qquad (1)$$

where I = interception amount in (mm)
W = the storm duration in (min)
R = rainfall intensity in (mm/min)
G = interevent duration in (min)
D = daily radiation in mm/min

and U, V, G and Z are constants to be determined. Although this equation is very general and involves many parameters, it was not more efficient than the following more simple equation: ($I = r + sLN(P)$ where P = rainfall amount in mm and s,r = constants to be determined) in estimating interception. So, it was suggested that the simpler equation be used in the experiment. In some cases where only a very broad estimation of interception is needed the author proposed the use of a very basic equation ($I = Pg = Pt$ where Pg = gross rainfall amount, Pt = the non-intercepted rainfall) to model interception.

Czarnowski and Olzewski (1968) proposed another general formula for the estimation of interception, e.g. $I = f(h*sqrt(sn))$ where f = a function to be determined, h = tree height, s = area of the plot of study and n = tree density in the plot. All the equations listed here can be used to estimate interception. But the last choice belongs to the researcher who is the only one to know the desired accuracy required in his work. Furthermore, the equations here are not the only ones existing in literature; there are many authors' models which can be used to quantify interception (Balek, 1977). The most physically based interception model is the one described by Fleming (1975).

2.5.2 Throughfall

It is the precipitation amount reaching the forest floor directly or by dripping from branches, leaves and twigs. Quantitatively, it is the difference between the gross precipitation and the sum of canopy interception and stemflow. The throughfall can be found by taking the water balance:

$$Pt = Pg - I - S \qquad (2)$$

where Pt = throughfall, S = stemflow and by the following formula:

$$Pt = a*Pg = b*N**a \qquad (3)$$

where N = number of storms in a given time span and a, b are constants (Helvey, 1967). Throughfall as a parameter has been evaluated in the tropical zones to be about 70 to 80% of annual precipitation (Mohr and Van Beueren, 1954).

2.5.3 Stemflow

Stemflow is the part of rainfall reaching the soil surface by flowing along the tree stem. This flow is generally minor compared to the interception amount. Stemflow volume taken as a percentage of seasonal or annual precipitation varies with forest types (Lee, 1980). It is therefore difficult to get a very accurate estimate of it. Because the stemflow can be very small, the errors on its measurement can be of the same magnitude as the total flow volume itself. For this reason stemflow is very often neglected in water balance calculation over forested areas. When the estimation of stemflow is required, it can be calculated as follows:

$$S = Pg - Pt - I. \qquad (4)$$

The components of this equation have already been defined in previous sections. Stemflow has been reported to vary from 0 to 2.65% on storm basis (Section 3.1). It was reported to be about 1% in the Ivory Coast (Huttel, 1975) and very high in a Puerto Rican forest where it amounts to about 18% (Kline et al., 1968).

2.5.4 Infiltration

2.5.4.1 Description of infiltration

It is the entry of rainfall water into the soil. Infiltration plays a very important role in the distribution of precipitation input after a rainfall event. As an example, the rainfall excess which generates runoff is computed by subtracting the infiltrated water from the overall water input. So, the accuracy of the estimation of runoff volumes and other hydrologic processes such as deep percolation and groundwater depends on how precise the infiltration has been estimated. The infiltration capacity of a soil (rate at which water infiltrates the soil) is generally influenced by its physical properties, i.e. degree of compaction of the soil, its moisture content, the permeability of the subsurface layers, the soil microclimate and the water quality (Lee, 1980).

a) Soil properties: The infiltration capacity is higher for coarse soils (sands) and lower for fine texture soils (clays). It decreases with decreasing permeability or hydraulic conductivity of the soil of study. The infiltration capacity is higher in a soil with a higher initial moisture content (Philips, 1957). When the soil is highly compacted, the infiltration capacity decreases.

b) Water quality: The water quality can be a limiting factor for infiltration (Hewlett, 1982). When the soil surface is bare, raindrop energy disperses colloidal materials which tend to plug soil pores and reduce infiltration. In forest zones the forest litter, humus and fine roots at the soil surface take the energy out of the raindrop and allow clean water to infiltrate.

2.5.4.2 Estimating infiltration

Through the years numerous equations were developed to model the infiltration process. One of the most well-known infiltration equations is the Horton decay equation (Horton, 1935). It can be expressed as follows:

$$f = fc + (f0 - fc)*EXP(-k*t) \qquad (5)$$

where f = infiltration capacity (in./hr)

f = infiltration capacity (in./hr)

f0 = initial infiltration capacity (in./hr)

fc = final infiltration capacity (in./hr)

k = empirical time constant (1/hr).

This equation has been successfully applied to tropical zones (Lafforgue, 1978). However, the problem often encountered with the Horton equation is the difficulty one can have in determining the constants f0, fc, and k in areas with little or no data (case of most developing tropical countries). Another equation widely used is the Green-Ampt equation derived from the well-known Richards equation (Richards, 1931). The Green-Ampt equation is defined as follows:

$$f = ks*(1 + Sav*(Ws - Wi)/F)$$

where f = infiltration capacity

ks = hydraulic conductivity

WS = saturation water content

Wi = initial water content

Sav = average capillary suction at the wetting front.

This equation is very handy and looks appropriate for tropical forest conditions because the parameters in the equation can be estimated with the soil properties in situ. Many other equations exist and can be used to model infiltration. They are Kostiakov's equation (Kostiakov, 1932) which is defined by

$$fp = k*t^{a-1} \qquad (6)$$

where fp = infiltration capacity

t = time

a,k = constants function of the soils initial conditions.

The Philips equation is expressed as follows:

$$fp = (s/2)*t^{-1/2} + ca \qquad (7)$$

where ca and s = constants.

These two last equations and others not mentioned here can be tried on tropical forest conditions to check their applicability to tropical watershed conditions.

2.5.5 Evapotranspiration

The ET estimation in the tropical rain forest is more complex than the usual measurement in lysimeter studies. This complexity exists because of the following reasons:

1) All ET processes, from canopy surface to soil surface, occur at the same time in the forest. So all physical and physiological factors influencing ET estimations are present. The physical factors are the soil

moisture storage capacity, the percentage canopy cover, and precipitation characteristics. The physiological factors are the leaf development stage, the stomatal resistance and the root growth.

2) Forest types can be different from one tropical area to the other. Perez et al. (1970) found that different tree species exist in the Puerto Rican rain forest compared to the Dominican Republic rain forest. The diversity between those species affects the precipitation interception rate by plant canopy.

3) In addition to the difference in canopy shape and structure, tree roots can be variable from one rain forest to the other. Several authors found diverse plant root distributions in the rain forest zone. Maxwell (1972), in the Miombo Forest in East Africa, reported that plant root could be found down to 23 ft. (7m). He also noted that root density varies from one tree specie to the other. He also found that first level tree roots were located in the top soil layer while a secondary root system reached the saturated zone and removed water from groundwater storage. In contrast with the above findings Ewel and Whitmore (1970) reported that tree roots form a tight mat on the surface and do not penetrate deeply into the soil for both the Puerto Rican and the Amazonian rain forests. These differences in root density and repartition affect the ET processes by

affecting the transpiration rate of trees which get their water supply from the soil moisture storage.

2.5.6 Estimating ET

There are many methods to determine ET values. The following is a summary of some of the most commonly used.

a) The pan evaporation method: This method uses a standard weather bureau class A pan to estimate evaporation. The pan with 4 ft diameter is 10 inches deep and is mounted 12 inches above the ground (Bedient and Huber, 1988). To measure evaporation the tank is filled and the water is monitored daily to know the water level difference, and there the evaporation depth is estimated. By multiplying the pan evaporation estimate by a coefficient less than one, one can also estimate evaporation from lake surfaces. Application of the standard Class A method under tropical conditions showed that with direct sunshine, the metallic pan becomes hot and the evaporation measurements are affected by the heating. For the above reason hydrologists have made an adaptation of the pan to fit the warm tropical conditions. The modification is basically done by protecting the pan against birds by screening it with a thin wire and coating the inside of the pan to prevent the heating. Another modification is to use fiberglass to reduce the heating and cooling of the pan. The results obtained by both methods were very good (Balek, 1977).

b) The field hydrologic water balance method: As its name shows, this method uses the hydrologic balance method on the area of study to calculate evaporation or evapotranspiration. Evapotranspiration is obtained by subtracting all other water losses from the gross precipitation and taking the value found as being the ET value. The field hydrologic balance method, although expensive to apply, has proven to give reliable ET values (Sengele, 1979). The method can be described as follows:

$$ET = P + GWI - GWO + SURFI - SURFO - DS \qquad (8)$$

where ET = evapotranspiration in inches

P = daily precipitation in inches

GWI = groundwater inflow in inches

GWO = groundwater outflow in inches

SURFI = surface water inflow in inches

SURFO = surface water outflow in inches

DS = variation of storage in inches.

ET regroups the following terms:

$$ET = T + It + Es + Eo \qquad (9)$$

where T = losses by transpiration

It = evaporation losses from intercepted water

Es = evaporation from soils

Eo = evaporation from open water bodies.

The term Eo can be calculated by the following equation:

$$Eo = k*(ews - ea) \qquad (10)$$

where k = coefficient function of the wind and atmospheric pressure

ews = saturation vapor pressure at the water surface temperature

ea = air vapor pressure.

c) The Penman equation: This equation has been nicely described by Bedient and Huber (1988). It is a combination of mass transport concepts and energy budget to calculate evaporation. The equation is defined as follows:

$$E = (\mathrm{DELTA}/(\mathrm{DELTA} + \mathrm{GAMMA}))*\mathrm{QN} + (\mathrm{DELTA}/(\mathrm{DELTA} + \mathrm{GAMMA}))*\mathrm{EA} \quad (11)$$

where E = free surface evaporation

DELTA = (es-esz)/(Ts-Tz) is the slope of the curve es vs. temperature by Brutsaert (1982).

QN = net radiation absorbed

es = saturation vapor at surface temperature Ts

esz = saturation vapor pressure at elevation z in millibar at temperature Tz

GAMMA = psychometric constant = 0.49 mm Hg °C

EA = mass transfer component characterizing the drying power of air.

The Penman equation can also be used to calculate ET with ET = f*E where f is a crop coefficient. The Penman equation has successfully been used in the tropics. However, the problems encountered in using this equation are related to difficulties in collecting the data required for its use.

d) The Priestly-Taylor method: The equation developed by Priestly and Taylor (1972) is used to estimate Eto, the potential evapotranspiration. It was first developed for short vegetation, but later Calder and Shuttleworth (1979) showed that it can be used for forest conditions as well.

It is a radiation based equation characterized by a factor alpha, known as the Priestly-Taylor coefficient. The alpha value compensates for the elimination of the aerodynamic component, such as wind speed found in the Penman equation. Priestly and Taylor experimentally found alpha to be close to 1.26. That result was confirmed by Stewart and Rouse (1977). Despite being an empirical equation it is based on sound physical ground (Butler and Riha, 1989). Another advantage of the Priestly-Taylor method as hinted earlier is that it reduces input requirements and is used where wind speed data and aerodynamic resistances are not available. The equation is given as follows:

$$\mathrm{Eto} = \mathrm{Alpha} * (\mathrm{NRAD} - \mathrm{G}) * \frac{1}{L_h} * (\mathrm{slopes}/(\mathrm{slopes} + \mathrm{psy})) \quad (12)$$

where Eto = potential evapotranspiration in $(\mathrm{kg} \cdot \mathrm{m}^{-2} \cdot \mathrm{S}^{-1})$

Alpha = Priestly-Taylor constant = 1.26

NRAD = Net radiation $(\mathrm{W} \cdot \mathrm{m}^{-2})$

G = soil heat flux $(\mathrm{W} \cdot \mathrm{m}^{-2})$

Slopes = slope of the saturation vapor density function in $(\mathrm{kg} \cdot \mathrm{m}^{-2} \cdot \mathrm{k}^{-1})$

Lh = latent heat of vaporization (2450 $j \cdot g^{-1}$ at 20°C

Psy = psychometric constant = 0.494 $g \cdot m^{-3} \cdot K^{-1}$.

The parameters described here will be analyzed in more detail later.

2.5.7 Runoff Processes

2.5.7.1 Generalities

Runoff refers to different processes that produce stream flow or overland flow. Bedient and Huber (1988) gave a good description of the various processes leading to the generation of surface runoff. They reported that during a given rainfall event, hydrological losses such as infiltration, depression storage and detention storage, must be satisfied before surface runoff begins. The excess water from the depression storage flows into small rivulets, and reaches the main channel where it is transported downstream by routing methods. Some of the infiltrated water can flow laterally through the root zone and give the inter-flow process. Water percolating to water table at great depth constitute the groundwater storage. When the percolated water emerges at the surface because of slope steepness, we have base-flow. The runoff process is generally represented by a hydrograph. A hydrograph is the plot of instantaneous discharges versus time at a given stream cross section or outlet. It allows the determination of the peak discharges necessary for design purpose. The hydrograph takes into account the physiographic and hydrometerological characteristics of the watershed and was clearly defined by Sherman (1932). The hydrometerological variables are (1) rainfall intensity and patterns, (2) the duration of the storm event, and (3) the aerial distribution of precipitation over the basin. The physiographic factors are (1) the size and shape of the drainage area, (2) the nature of the stream network, and (3) the slope of the main channel. The shape of the hydrograph is contributing to the various components of the hydrograph itself. The different constituents of the hydrograph are (1) the lag time is the time from the center of rainfall excess to the peak of the hydrograph; (2) the time of rise is the time from the beginning of runoff to the time of peak; (3) the time of concentration is the time taken by water to propagate from the most distant point of the watershed to its outlet; and (4) the time base is the total duration of the direct runoff hydrograph (Fig. 5). One form of hydrograph, the unit hydrograph introduced by Sherman (1932), is widely used to compute runoff discharges. The unit hydrograph represents one inch of direct runoff in the basin. The proportionality relationships between the natural hydrograph ordinates and the unit graph ordinates help compute the latter when the first are known. There are also nonlinear methods that can

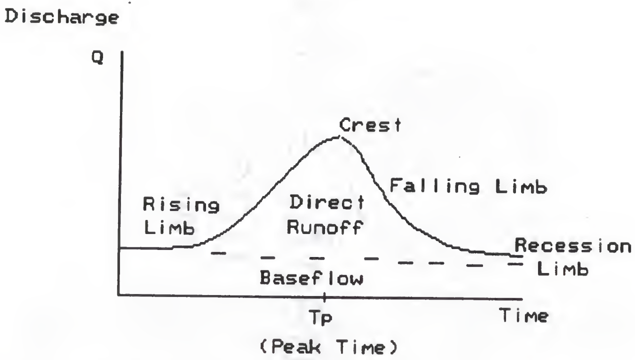


Figure 5. Description of a hydrograph.

be used to determine runoff: the kinematic wave method is one of them.

2.5.7.2 Runoff in tropical forest zones

To get a better understanding of the runoff process in tropical forest zones it is very important to underline the various factors which affect runoff in a given study area. These factors are

1) The intensity and duration of precipitation
2) The rate of interception by vegetation and the ET process
3) The rate of infiltration and throughflow into the soil
4) The nature of vegetation cover
5) The nature of the soil mantle
6) The nature of soil surface in terms of roughness
7) The steepness, length, and slope aspects.

Among all important factors, the following three are key conditions for runoff generation in tropical forests. They are

a) The occurrence of canopy openings called "gaps," through any one of the following combinations: tree fall, forest fires, leaf fall from deciduous trees, soil poisoning due to forest depletion.

b) Bare ground surface under thick tropical forests, in terms of undergrowth and leaf litter.

c) Occurrence of intense rainfall both as high incidence short storms and as prolonged heavy rainfall. These conditions have been proven to be very important on high steep relief areas as well as less steep surfaces (Oyegun, 1980).

Because of the factors above mentioned, runoff analysis in the tropical forest is rich in conflicting results. Whenever the term forest is mentioned, the first thing that comes to mind is a picture of a reduced runoff because of the interception of rainfall by the tree canopy (Lee, 1980). This conception is in part true, but in reality there is no forest in the world which has no gaps. Gaps, as reported by Douglas and Spencer (1985), create a stochastic rainfall distribution which in turn affects runoff occurrence in the forest. Because of the random repartition of gaps, the difference in soil types and rainfall intensities, efforts to measure or estimate runoff often give contrasting results. Here is a summary of a few studies under tropical forest conditions.

Nortcliff and Thornes (1981) found very low runoff in their study of runoff on small catchments in a tropical watershed. This low runoff, they said, was due to a high infiltration rate of the top layer of latosol in that area. The same result (low runoff) was also found by Roose (1980) in his study of runoff over parcels in the Ivory Coast. However, the results from parcels and small catchments should not be extended to large catchments without great attention. The interactions of different parameters which generate runoff in large basins may involve certain factors (emergence of base-flow, etc.) which are rarely observed in small basins. In contrast to the two first results the same authors (Nortcliff and Thornes, 1981) found very high runoff volumes in a tropical forest study in Queensland, Australia. The high runoff volume observed was due to a decrease of permeability after the first 10 cm of the top soil. Therefore, the soil was quickly saturated and runoff was thus generated. Similar results were found by Leigh (1978) in a runoff study over a Malaysian watershed.

From the above results, it can be seen that the only way runoff estimation in the tropical forest can be accurate is to be able to access correctly the variables such as rainfall intensities, vegetation cover and the soil types of the area of study. This can be a very tedious task since most of the catchments of tropical developing countries are not gaged. Research needs to be directed towards those zones if one wants to get a better understanding of the runoff process in tropical forest watersheds.

2.5.8 Streams, lakes, swamps and flow regimes

Streams, lakes and swamps are known to be impervious areas, i.e. they don't infiltrate water. Lakes are open water bodies, while swamps are water bodies covered by vegetation. Streams are water bodies flowing in beds created by continual water flow. Streams, lakes, and swamps are generally considered to be open areas in the forest although swamps do not completely fit that classification. Swamps and lakes often delay the surface runoff outflow by days, weeks, or months. They act as sponges by absorbing and gradually releasing water. Flow regimes are related to the climate. Balek (1977) gives the following characteristics of flow regimes of tropical zones:

a) They are characterized by a minimum discharge during winter seasons and a maximum discharge during summer months, i.e. July, August and September north of the equator and February, March and April south of the equator.

b) The equatorial flow regime has two peaks: one in autumn and the other in summer. As shown above, climatic variations are key factors which influence flow regimes in the tropics.

2.5.9 Groundwater

2.5.9.1 General concepts

The infiltration of water at the soil surface can be viewed as two processes: a) Soil moisture is soil water in the unsaturated zone, while the second term b) groundwater represents water below the water table.

2.5.9.2 Soil moisture

The soil is represented by soil particles and pores. These pores contain air and water. A volume (V) of a soil can be viewed as the sum of Vs (solid matter volume), Vw (water volume), and Va (air volume) so that V = Vs + Vw + Va. Soil moisture in an unsaturated soil is the parameter Theta = Vw/V (Vw and V are the volumes defined above). At saturation the value of theta is eta = (Va + Vw)/V and is called soil porosity. Water flow in the soil is governed by the energy equation:

$$H = P + Z + O \tag{13}$$

where H = potential energy

P = soil pressure

Z = gravity potential

O = osmotic potential.

Water flows from zones of high potential to zones of low potential. The flow discharge from a given cross-section is

$$Q = A*K*DH/L \tag{14}$$

where A = cross sectional area including pores and grains

Q = discharge from the cross section

K = hydraulic conductivity

DH = hydraulic head difference

L = soil column length

2.5.9.3 Groundwater

Groundwater is found in the saturated zone. The surface of the zone of saturation is a zero pressure zone called the water table. Groundwater occurs in permeable zones called aquifers. There are various types of aquifers.

An unconfined aquifer is an aquifer in which the zone of saturation is not beneath an impermeable layer (confining unit). A confined aquifer is an aquifer held between confining units. Water in a confined aquifer is under pressure and, as a consequence, will rise into wells penetrating those formations.

2.5.9.4 Characteristics of groundwater and soil moisture in the tropical forest

Groundwater is a very important water resource in the tropical forest zone because water demand is high and surface water is often polluted. Sometimes, subsurface water is the only water resource available in growing cities (Balek, 1977). According to the same author, more than 50% of tropical African cities depend on groundwater supply. Because of the high water demand, the high evapotranspiration, groundwater depletion is becoming a topic of major concern. So, groundwater use needs to be regulated. To compensate for water losses groundwater recharge occurs by two main factors: a) rainfall and b) infiltration of water from streams and lakes or swamp bed sides. There is no atmospheric humidity to produce snow like in temperate zones. Long time rainfall with infiltration is a good way to replenish groundwater; short-term rainfall does not profit for much. The water table generally rises several months after the rainy season (Balek, 1972). This water storage can cover water needs of plants when the water table is not too deep. However, if ET is too high, or water demand for consumption is too high, the water storage is quickly depleted.

The reason for the quick depletion is basically due to the fact that most of the tropical aquifers are unconfined and the parent rock is highly impermeable (Rougerie, 1960). Figure 6 describes the type of aquifers over the precambrian shield.

2.5.9.5 Other factors affecting groundwater in the tropical forest

The removal of forest litter increases infiltration (Tsukamoto, 1975). One factor which enhances the removal of forest is forest fire. There are few studies related to the effects of forest fire on groundwater. The intensity of the burning is the factor which has more incidence on subsurface water. Forest burning increases the throughfall, reduces transpiration, and favors runoff. This fact is supported by Megahan (1981) who found an increase of runoff due to the removal of forest litter by fire. This happens as a result of the sealing of the soil surface which favors runoff at the expense of the infiltration process which feeds groundwater storages. So, it appears that forest fires have a negative effect on groundwater replenishment.

The effect of forest canopy replacement by tree plantation (Hamilton and King, 1983) has not given a conclusive result as in how the replacement influences groundwater storage. The same authors investigated the transformation of tropical forests into grasslands or savannahs for grazing purposes. They found a decrease of ET and interception due to the change and that only the characteristics of the soil can limit infiltration and groundwater replenishment.

Certain factors, like forest fires and transformation of the forests into other vegetations, need to be addressed for a better groundwater evaluation in the tropical forest zones.

2.6 Watershed Modeling

2.6.1 General Concepts

High-speed computers has made hydrologic simulation or modeling possible. Simulation is the indirect investigation of the response of the behavior of a system. The two main categories in modeling are the parametric and the stochastic modeling.

a) The parametric modeling is the development of relationships between physical parameters in the hydrologic events and the use of these relationships to generate or synthesize nonrecorded hydrologic responses. This approach is also known as deterministic.

b) Stochastic modeling is a method that uses statistics concepts to solve hydrologic problems. It usually involves the generation of nonhistoric hydrologic sequences to which certain levels of probability are attached.

Although the various methods of hydrologic system simulations have certain basic differences, they all share two characteristics of prime importance:

1) They depend on historical records for calibration or verification.
2) They are assumed to be stationary in time (Amorocho and Hart, 1964).

Two main trends exist in the parametric modeling approach. They are the black box approach and the conceptual approach. In the black box approach, the analyst only considers the output of the hydrologic system to a given input sequence to the basin. The internal work of the system is of minor importance. In the conceptual approach, the hydrologic system is modeled by a series of equations which describe the actual internal physics of the system (Crawford and Linsley, 1966). In this approach, the knowledge of the physics of the system is the limiting factor. In parametric hydrology there are two very popular methods: the linear and the nonlinear concepts. For a linear system one assumes that the input to the system at a given time produces an output which does not interact with any other input. On the other hand, the nonlinear approach assumes that a given output is the result of complex interaction between many input functions. Many models are available nowadays in a wide range of continuous and event models. A continuous model is one which simulates the response of a system to a series of continual inputs, while event models are more inclined to simulate short-term events (flash floods, hurricanes, etc.).

2.6.2 Modeling the Tropical Watersheds

The above concepts can be applied to hydrologic simulation anywhere in the world. However, because of the characteristics of the tropical zones, equations modeling hydrologic processes are not exactly the same as those used in temperate zones. The difference resides basically in the quality of hydrologic variables in both regions. As an example, the absence of ice in tropical zones excludes the existence of complex snow determination routine in a conceptual tropical model. As a result, models developed in temperate regions cannot be applied blindly to tropical conditions without a careful calibration (Balek, 1977). For the above reasons, some models have been modified to fit tropical conditions. The Nigerian version of the Stanford model developed by Egbuniwe (1981) is an example of such modified models. Balek (1977) also developed a model related to water flow simulation in Dambos (swamps). The problem of most hydrologic models in developing tropical countries is the lack of data for serious hydrologic simulation. Most of the time the data are too "short."

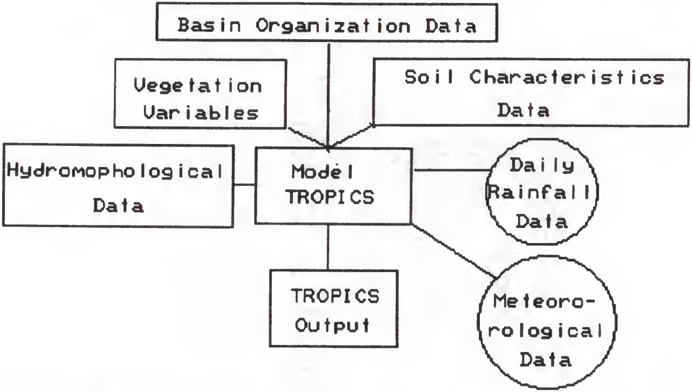


Figure 6. Types of input data.

CHAPTER 3
METHODOLOGY OF MODEL DEVELOPMENT

3.1 Modeling Overview

1) The basin to be studied is subdivided into square elements of different sizes. Smaller grid sizes are used in rough terrains, while larger ones represent smooth topographical areas. This procedure reduces the overall element number and decreases computer time. Within an element (regardless of its size) most of the hydrologic variables are lumped, and soil characteristics are assumed to be homogeneous. It is further assumed that each square sub-basin is hydrologically stable, i.e. changes in parameter values during an event will not alter the overall response of the whole watershed when everything else is held constant. Figure 7 is a representation of a basin, after it has been subdivided into elements.

2) Find the size and flow direction (steepest slope direction) of each element. Both parameters are computed from a topographic map of the basin and are inputs to the model. The slope direction is very important since it determines how the flow will be routed from element

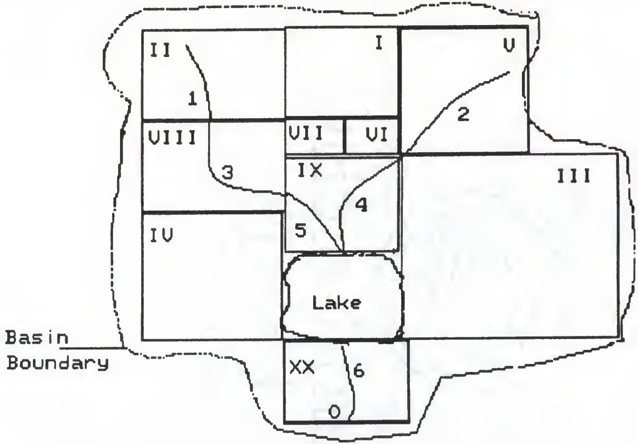


Figure 7. Subdivision of a basin into different grid size elements.

to element. It is therefore convenient to have a clear map where topographic contours can be seen.

Flow can take any of the 8 directions shown in Fig. 8. The directions are west, east, south, north, NE (1st quadrant of the trigonometric circle), NW (quadrant II), SW (quadrant III), and SE (quadrant IV). For practical purposes, the major directions north, south, east, and west are chosen for overland flow routing. Therefore, when flow occurs in one of the four quadrants, it is divided into a vertical component $\vec{Q}_V$ and in horizontal component $\vec{Q}_H$, so that:

$$\vec{Q} = \vec{Q}_V + \vec{Q}_H \tag{15}$$

The trigonometric relationships (Fig. 9) help direct the flow from one element to the elements adjacent to it. The angle α (flow angle with respect to the horizontal line) is counted counter-clockwise from the bottom side of the element to the left following a trigonometric orientation. Once Q is known, the formulas (Fig. 9) help compute Q_H. Knowing Q_H and Q, Q_V can be calculated by

$$Q_V = \sqrt{Q^2 - Q_H^2} = Q\sqrt{1 - \cos^2\alpha}$$

or

$$Q_V = Q_H \cdot |\tan\alpha| \quad . \tag{16}$$

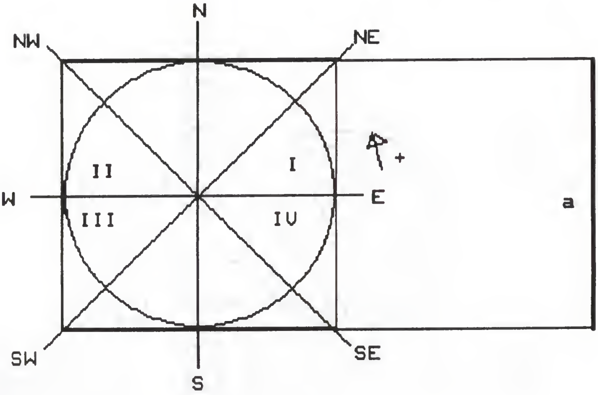


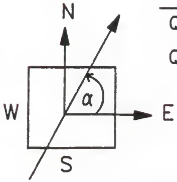
Figure 8. Different flow directions in a square of side 2.

Figure 9. Trigonometric formulas and flow directions.

Flow Direction

Trigonometric Representation of the Flow Angle

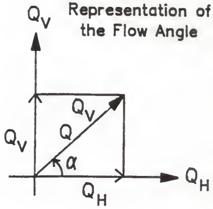
(1)



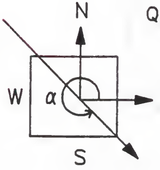
$$\vec{Q} = \vec{Q_H} + \vec{Q_V}$$

$$Q_H = Q.\ \cos\alpha$$

$$0<\alpha<\pi/2$$

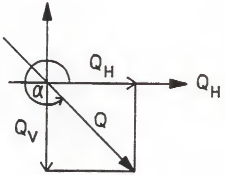


(2)

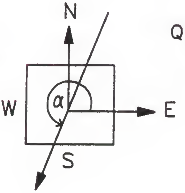


$$Q_H = Q.\ \cos\alpha$$

$$3\pi/2<\alpha<2\pi$$

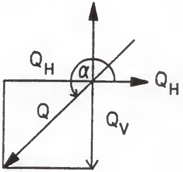


(3)

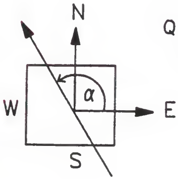


$$Q_H = -Q.\ \cos\alpha$$

$$\pi<\alpha<3\pi/2$$

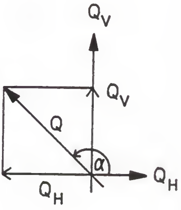


(4)



$$Q_H = -Q.\ \cos\alpha$$

$$\pi/2<\alpha<\pi$$



or

$$Q_V = Q|\sin\alpha|$$

3) In this step the major channel network is defined. The channel system is divided into segments between different junctions. The channel network receives its flow from the element it crosses, i.e. the flow from an element having a channel segment is totally directed into that channel reach. This concept introduced by Monke and Huggins (1966) allows a link between channel and overland flow. It is therefore imperative to distinguish between elements having channel segments and those that do not, since the flow routing procedure is not the same for those two types of elements (the flow from elements which have channel reach is directed into the channel while flow from no channel elements is divided into horizontal and vertical components to "feed" adjacent elements). Figure 10 shows an example of a channel network.

4) Define the hydraulic interconnections between different elements in the basin, i.e. the different flow paths of overland flow and channel flow from the watershed boundaries to its outlet. Find impervious areas within the watershed (lakes, urban zones, etc.). Number the elements

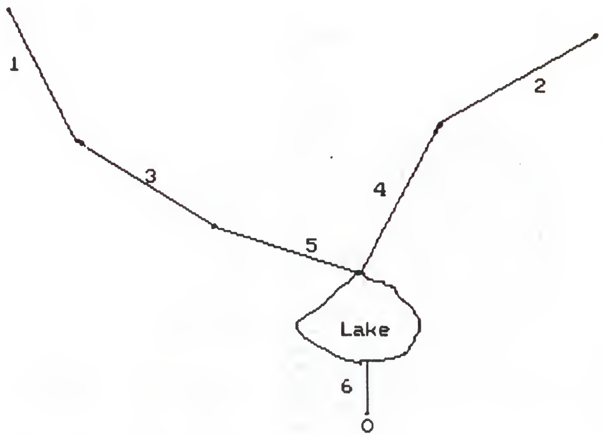


Figure 10. Channel network with reaches and junctions.

from 1 to N (N = total number of elements). Assign a sequence number to each square grid. That number determines the routing order of the flow through that element to the adjacent elements and down to the basin outlet. The following is a detailed description of the flow routing procedure. The elements are classified into different levels.

1) The first level elements or L_1 elements--The elements of level L_1 are, in general, the boundary elements. They do not receive overland flow from any other elements. They provide flow for elements located down stream. In the routing scheme, overland flow is computed first for the first level elements. An example of first level elements is the series of elements 1, 2, 3, 4, and 5 in Figure 7. For computation purposes flow is not allowed to get out of the basin except at the outlet 0. As an example, Q_{V3} (the vertical flow component of element 3) and Q_{V4} (the vertical flow component of element 4) will be forced to be equal to 0.0 (i.e. $Q_{V3} = 0$, $Q_{V4} = 0$) and the overall flow from those elements will be the horizontal flow component which will represent the total flow coming out of that element.
In another word, irrespective of the flow direction given by α computed in step 2 $Q_{H4} = Q$ (Fig. 7).

2) The second level elements or L_2 elements--The second level elements receive flow from first level elements only.

The flow in these elements is entirely determined when the flow from level 1 elements is defined. The next step in the flow routing procedure is to calculate the flow from the second level elements using the continuity equation. In the example Figure 7 L_2 elements are: elements 6, 7, and 8.

3) The third level elements or L_3 elements--The flow from the third level element is completely determined once the flow from preceding levels (L_1, L_2) are known. The third level element in the example Figure 7 is element 9. Once again the continuity equation is used on element 9 to calculate the outflow hydrograph at different time intervals.

4) Proceed to the next level until all elements are classified in their respective level.

5) Supplementary note on elements classification--In addition to the fact that elements are classified by levels, they are also defined into classes for modeling purposes. The classification is performed according to the following conditions:

1) When the element I of the watershed has a channel segment and drain to a lake within the basin, the element is first class element, i.e. Class (I) = 1.

2) When the element I drains to a lake and has no channel segments crossing, it is a second class element, i.e. Class (I) = 2.

3) When the element doesn't drain to a lake and has a channel segment, it is a third class element, i.e. Class (I) = 3.

4) Finally, when the element I has no channel and doesn't drain to a lake, it is a fourth order element, i.e. Class (I) = 4. This classification allows the model to account for lakes or reservoirs in the basin.

Along with the levels and classes it is also necessary to define the adjacent elements to a given element I. This will define the flow routing order from element to element down to the outlet of the watershed.

Channel element characteristics

The channel segments are entirely defined within the element which contains them. So, the inlet and the outlet of a channel segment should be located in the element containing the channel segment. An element cannot have more than two channel segments crossing it. The channel segment and the element size should be chosen so that the travel time be closer to the time increment chosen in the model, i.e. 1 hour. For practical purposes, channel segment length should be more than 1 km. So an element with a channel cannot be less than 1 km^2. Once the channel segments are defined, they are numbered from 1 to NToTC (total number of channel segments in the watershed), (Fig. 10) following the overall element classification described previously. One of the strengths of TROPICS compared to other distributed grid shape models is its ability to handle more than a channel segment in an element. This advantage, however, complicates the channel flow computations within the element. To solve that problem, the channel segments are converted into the following integer matrixes:

JJ(I): Channel segment number in the element I when that element has only one channel segment crossing it.

$JJ_1(I)$: First channel segment in the element I.

$JJ_2(I)$: Second channel segment in the element I.

$JJ_1(I)$ and $JJ_2(I)$ are used when the element has two channel segments crossing it. The use of the matrix form helps to account for the adjacent channel in the channel flow routine. Figure 11 gives an example of notations in channel flow. $Nume(I_5) = 1$ means that the element #7 has only one channel segment crossing it. $NADJAC(JJ(I_5)) = 2$ explains that there are two channel segments adjacent to channel #7 which is also $JJ(I_5)$, i.e. $JJ(I_5) = 7$. In this case, $NSC(JJ(I),1) = JJ_1(I_4) = 5$ indicates that the first channel segment adjacent to channel segment #7 is channel segment #5 which is also $JJ_1(I_4)$. $NSC(JJ(I_5),2) = NSC(7,2) = JJ_2(I_4) = 6$ means that $JJ_2(I_4) = 6$ is the second channel

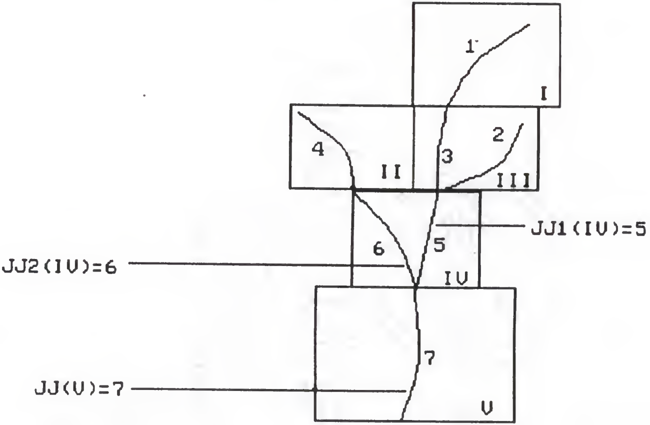


Figure 11. Possible channel configuration.

segment adjacent to channel #7. Nume (I_4) = 2 means that the element #I_4 has two channel branches crossing it. This notation is true for each of the channel segments considered in Figure 10. It is also essential to link the channel together in the channel flow scheme. A subroutine called CHAN finds the adjacent channel segment to each given channel element once it is called. For this first release of TROPICS, the maximum number (nume (I)) of channel segment in a given element I is 2. So is the maximum number, NADJAC(JJ(I)) of a channel segment adjacent to a given channel segment JJ(I).

3.1.1 Input Requirements

Tropics being a distributed physically based model requires a relatively large amount of data to be run. The data needed can be classified in the following categories (Fig. 6).

a) The basin organization data. This data is case data set of the model. It gives the ordering of elements into different levels and classes. This helps set the channel, non channel element and lakes and the flow routing pattern.

b) The hydromorphological data. This data set describes the channels and their slopes; the overland flow slopes and water divides for subbasins or element delineation.

c) The Daily Rainfall Data for the Week. This is the single most important data. Other variables in the model are predicted from the rainfall data.

d) Meteorological Data. Daily temperatures and radiations are necessary for the computations of ET values using the Priestly-Taylor method.

e) Vegetation Data. This data type helps calculate the canopy density for each element. It comprises parameters such as the number of trees per unit area and the different type of tree diameter size of the element of study.

f) The Soil Characteristic Parameters. This is the data set necessary to calculate infiltration, depression, storage and groundwater flow. The hydraulic conductivity, the field capacity, and the wilting point water content fall in that category of data. Tropics link all these data together to get the outflow discharge at the outlet of the tropical basin. Other details on the inputs are discussed in chapter 3.5 and throughout the model description.

3.1.2 Output of the Model

Tropics can reprint the input data files (optional). The user can activate or deactivate the printing of the input in the overall output by entering 1 or 0 when running the model. Option 1 means the input is printed; Option 0 means the opposite. In the overall output structure, the input files are printed closely to the output variable they describe; i.e. the temperature input data file is printed with the predicted temperature values. The word input is used in all the headings preceding the printing of an input data file for clarity in the reading of the output of the model.

In addition to the input data files which are optionally printed, here are the main variables tropics outputs.

a) The output from subroutine order which indicates the possible setting of non-zero rainfall values leading to the setting of rainfall values into independent events by subroutine REORD.

b) The output of REORD is also given to show the number of events the model will be using for its computations. Newc is the number of different events from Tropics.

c) The program gives the predicted temperature values used in computations to obtain the ET values.

d) The predicted ET values by the Priestly-Taylor method are given.

e) The throughfall value, i.e. the rainfall values in excess of interception are given for each of the elements of the watershed.

f) The canopy density which is a very important parameter in this model is calculated for each element.

g) The rainfall excess (runoff) as well as the infiltration values are given for each element. In the output file, runoff is called excess and infiltration infilt.

h) In the case where the channel velocity, and other channel characteristics are not given, their predicted values are given in the output file.

i) The key output of the model (TROPICS) is the hourly discharges values QOUTOT.

j) The discharges obtained are plotted in output. The numerical output of Tropics consists of the matrix QOUTOT(K,NEL) with K = 1,168, and NEL is the last element of the watershed, i.e. the outlet element. Table 1 is the listing of the output and Figure 12 shows a typical graph which can be obtained when running TROPICS.

3.1.3 Algorithm, Subroutines and Flow Chart In TROPICS

3.1.3.1 General subroutines and algorithm. The overall algorithm of TROPICS is defined by the Flow Chart in Figure 13. The model starts by setting the raw precipitation data into a format readable by the computer. Two subroutines--ORDER and REORD--are used for that purpose.

Subroutine ORDER. ORDER takes the raw precipitation data and organizes it by setting into events of non-zero rainfall. It finds the starting time (NFirst) and the ending time (NLast) of the non-zero event. It also counts the number NCount of non-zero rainfall periods.

Table 1. The output configuration.

Time (hr)	Discharge (m^3/s)
1	Q_1
2	Q_2
3	Q_3
.	.
.	.
.	.
K	Q_K
.	.
.	.
.	.
.	.
.	.
.	.
.	.
.	.
.	.
168	Q168

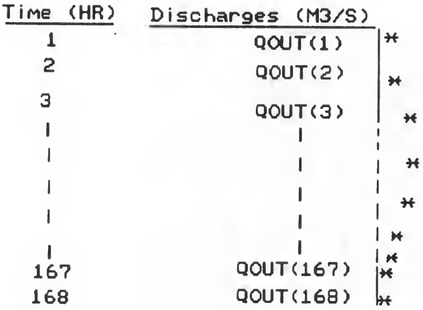


Figure 12. Graph of typical hydrograph obtained from running TROPICS.

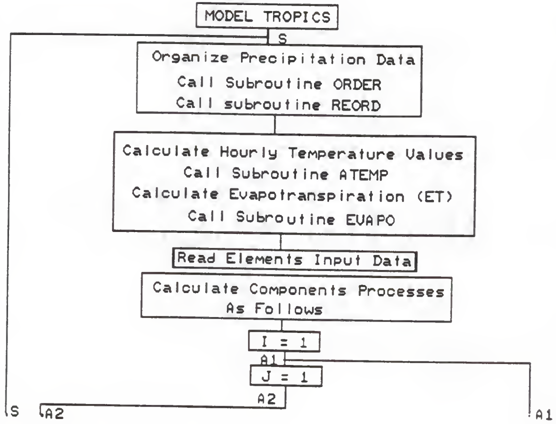


Figure 13. Algorithm of TROPICS.

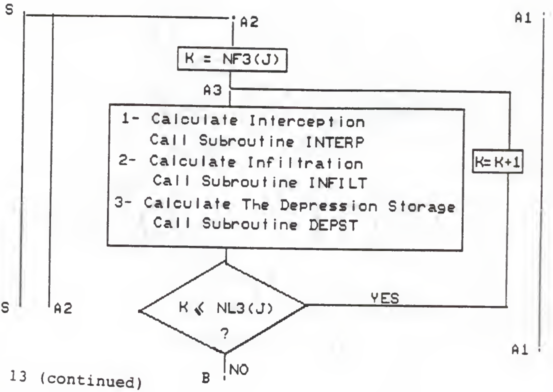


Figure 13 (continued)

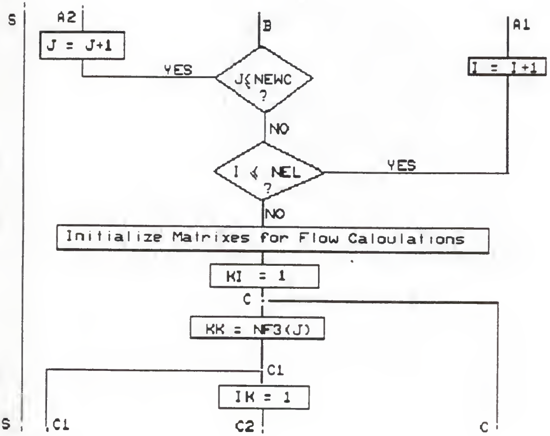
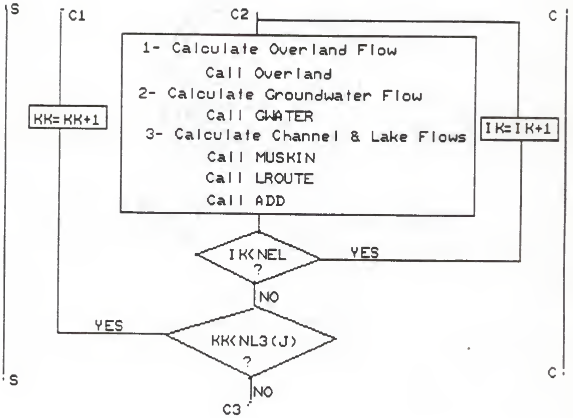


Figure 13 (continued)


S
C1
C2
C
1- Calculate Overland Flow
Call Overland
2- Calculate Groundwater Flow
Call GWATER
3- Calculate Channel & Lake Flows
Call MUSKIN
Call LROUTE
Call ADD
KK=KK+1
IK=IK+1
IK<NEL ?
YES
NO
KK<NL3(J) ?
YES
NO
S
C
C3

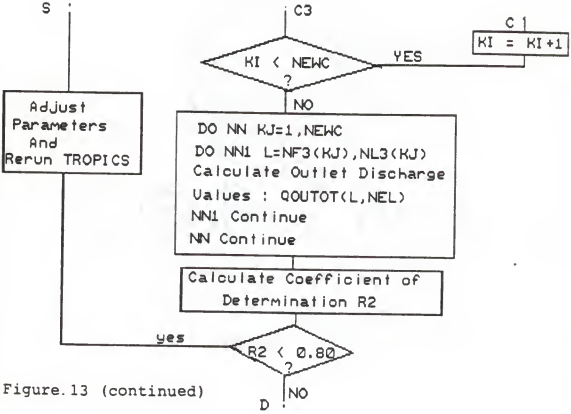
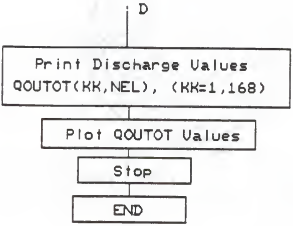


Figure. 13 (continued)


D
Print Discharge Values
QOUTOT(KK,NEL), (KK=1,168)
Plot QOUTOT Values
Stop
END

Subroutine REORD: This routine reorders the data obtained from subroutine ORDER into independent events separated by at least the minimum inter-event time T_L. The time between events is T_B. In case of independence, T_B should be larger or equal to T_L. Figure 14 shows the division of rainfall data into events. NEWC is the total number of independent events. NFirst(J) is the starting time of the event J and NLast2(J) is the ending time. T_B is defined as follows, $T_B(J)$ = NFirs2(J+1) - NLast2(J). J is the event number. RLast2(J) is the rainfall data corresponding to time NLast2(J) and NFirs2(J) is the rainfall value corresponding to the time NFirs2(J). Subroutine REORD is a key subroutine in TROPICS, because most of the simulations are carried on event basis, i.e. the processes are simulated between NFirs2(J) and NLast2(J).

Next to the precipitation calculations comes the estimation of the evaporation. Before evaporation is calculated using subroutine EVAPO, the temperatures are estimated by subroutine ATEMPE. ATEMPE uses daily temperature as input and calculates hourly temperatures using a sinusoidal function described by

$$T(I,J) = TBAR(I) + DT(I) \cdot Sin(0.2618 \cdot J - 1.571) \qquad (17)$$

where $T(I,J)$ = temperature during the day I at hour J of the day

$T_{Bar}(I) = (Tmin(I) + Tmax(I))/2$ is the daily mean temperature

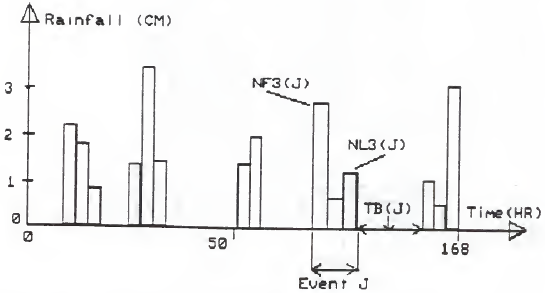


Figure 14. Organization of rainfall data into independent events.

$T_{min}(I)$ and $T_{max}(I)$ are, respectively, the daily minimum and maximum temperatures.

$DT(I) = (T_{max}(I) - T_{min}(I))/2$ is half of the temperature difference

The output from ATEMPE is used by subroutine EVAPO. Subroutine EVAPO uses the Priestly-Taylor formula to calculate $E_o(I,J)$ which is the evaporation on Day I at time J of the day. The way the computations are carried out will be explained later in the process modeling chapter.

In the following steps the model reads the elements inputs information because some of this information is used to calculate the component processes such as infiltration, interception, etc. When the element input file is entered, the model starts the computation processes. This is done by incrementing the element (Index I). For each element the model calculates the component processes for each event (Index J). The time increments start by the starting time value of the event J, i.e. NF3(J) and stops at NLast3(J). When all the elements are processed, and the last element is covered, the computer starts the next step. The subroutines utilized in the component process calculations are as follows:

The function subprogram DCOMP calculates the canopy density within each element.

Subroutine INTERP. Interp calculates the interception values during the week. It does it by making a water balance calculation from the rainfall input. The output from the subroutine is the throughfall, known as parameter THRG in the model. Because of the importance of tree canopy reducing the amount of water reaching the soil, an accurate determination of the canopy density is very important if one wants to obtain a good estimate of THRG with subroutine Interp.

Subroutine INFILT. Subroutine Infilt calculates the infiltration through the soil using the Green-Ampt method. It calculates the infiltration value FIL for each different time interval. When FIL is calculated, the runoff excess in terms of water depth is calculated, i.e. EXCESS = THRG = FIL. Infiltration values within subroutine INFILT are calculated using a Newton Raphson method. Subroutine COMPUF does the computations.

Subroutine RESET within subroutine INFILT set the initial water content for simulation at the next time step. Excess is the rainfall input to the next subroutine which is SUBROUTINE DEPST: DEPST is the Depression Storage Subroutine. It calculates the depression storage in each element and output RUNOF which is the runoff water depth in the watershed.

When the initial characteristics of channel segments such as the mean velocity (VM), the initial discharge QQo, the initial water dept yyo, and the channel initial water level HWC are not known, they can be estimated using subroutine CHANIP. The latter first determines a relation $Q = \alpha A^{\beta}$ (where Q = discharge, A = land area in km^2), using regression data on the area. Once the relation $Q = \alpha A^{\beta}$ is defined, by using the formula of Chapter 2.1, the value of Von, yyo, QQo, and HWC can be defined. Subroutine MEDFIT defines the best regression α and β values within subroutine CHANIP. Subroutine ROFUNC and SORT are used by MEDFIT for calculations.

3.1.3.2 Subroutines of Flow Calculations.

Overland flow

Subroutine OVLAND calculates the overland in TROPICS. Overland is computed for all elements without exception. The outflow from the subroutine is QOVA(K,I) where K is the time value and I the element rank or number. The rain input to subroutine OVLAND is the output PRUNOF from the depression storage subroutine DEPST. OVLAND has 2 subroutines: ADJACE and COMPY. Subroutine ADJACE is the key subroutine in Ovland. For every simulation time step ADJACE goes through all the elements adjacent to an element I adds all the overland flows together and gives the inflow QBAR2 so that the flow can be routed through the element. Subroutine ADJACE prepares the inflow values use by SUBROUTINE COMPUY. The latter performs the flow routing through the given element by combining the Darcy-Weisbach and the Continuity equation. COMPUY calculates YY(K,I) and QOVA(K,I), respectively, the overland flow depth and discharge. COMPUY utilizes the Newton Raphson method to calculate the discharge from the elements.

Groundwater Flow. Subroutine GWATER calculates the groundwater released from the soil to channels. Subroutine GWATER gives the groundwater release GWAT from element with channels. In this model the groundwater is not routed from one element into the adjacent element, only the groundwater released into channels within an element is considered. When the element has only one channel segment, the total groundwater from the element is GWR(K,I) = GWAR(K,JJ(I)), where JJ(I) is the channel segment lying in the element I. When the channel has 2 channel segments, the overall groundwater flow out of that element is GWR(K,I) = $\mathrm{GWAT}(K,JJ_1(I)) + \mathrm{GWAT}(K,JJ_2(I))$ where $JJ_1(I)$ and $JJ_2(I)$ are the two channel segments in the element. Soil moisture is also calculated in subroutine GWATER. Subroutine GWATER has a subroutine called COMPTH which iteratively solves the groundwater equation. FUNCTION HANDLE and HDLR are used to handle floating point errors in subroutine COMPUY and COMPTH, respectively.

Channel Flow. Three types of channels are identified in the model. They are:

1) Channel with only one adjacent segment with no lake inflow.
2) Channel receiving from the lake (only if such channel exists)

3) Channel with two adjacent segments.

For each case the inflows are calculated and the outflows are obtained using the Muskingum equation. It is necessary that the channel flow be calculated after overland flow and groundwater flow are calculated. Because both affect channel flow the total outflow from the element with channel is QOUTDT(K,JJ(I)). It is the sum of all outflows taking place in the element. The actual channel flow calculated by Muskin is QCO(K,JJ(I)).

Lake Flow. Subroutine LROUTE calculates the flow through a lake or reservoir within the element. LROUTE goes through all the elements draining to the lake and adds their flows together at the time t - 1 and t and routes the flow through the lake. The flow equation is solved by iteration using the Newton-Raphson method. The outflow from the lake is QoL(K). Once all the flow has been calculated for each element for each time step and for each event, the discharge matrix Qout(168,NEL) is defined. Then the plotting subroutine PLOT is called to plot the hydrograph, and the program ends the simulation.

3.1.3.3 Description of the Flow Chart. The flow chart (Fig. 15) in TROPICS was built to describe the flow portion of the model. It explains the interactions between overland flow, groundwater flow, channel and lake flow. It also shows the flow continuity down to the basin outlet. The simulation of flow processes is performed on an event basis. An event

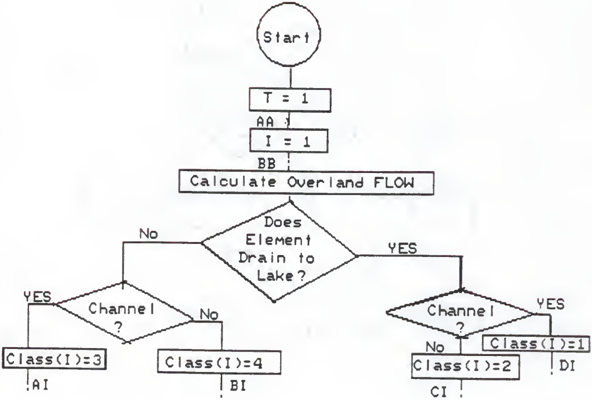


Figure 15. Flow chart of TROPICS.

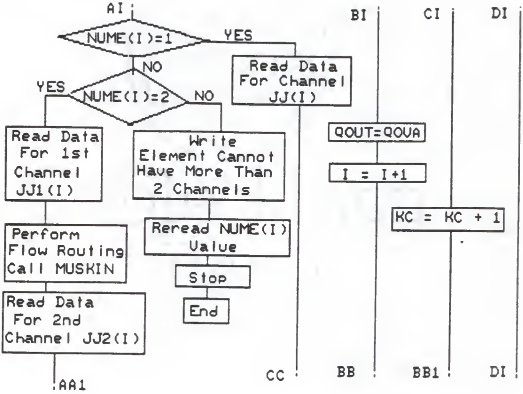

AI
NUME(I)=1
YES
NO
BI
CI
DI
Read Data For Channel JJ(I)
YES
NUME(I)=2
NO
QOUT=QOUA
Read Data For 1st Channel JJ1(I)
Write Element Cannot Have More Than 2 Channels
I = I+1
KC = KC + 1
Perform Flow Routing Call MUSKIN
Reread NUME(I) Value
Stop
Read Data For 2nd Channel JJ2(I)
End
CC
BB
BB1
DI
AA1

Figure 15 (continued)

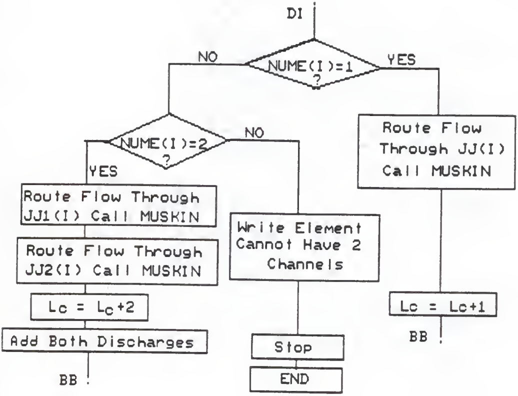

DI
NUME(I)=1 ?
NO
YES
NUME(I)=2 ?
NO
YES
Route Flow Through JJ(I) Call MUSKIN
Route Flow Through JJ1(I) Call MUSKIN
Route Flow Through JJ2(I) Call MUSKIN
Write Element Cannot Have 2 Channels
Lc = Lc+2
Lc = Lc+1
Add Both Discharges
Stop
END
BB
BB

Figure 15 (continued)

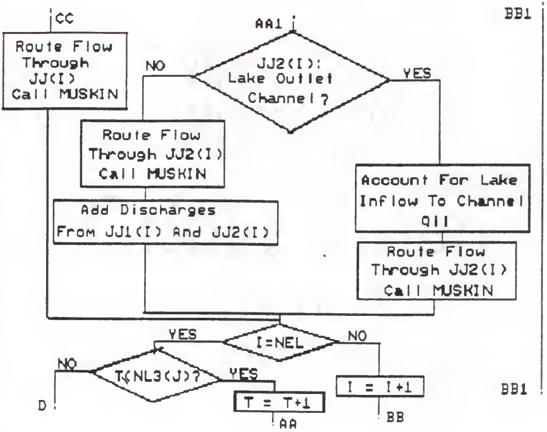

CC
Route Flow Through JJ(I) Call MUSKIN
AA1
JJ2(I): Lake Outlet Channel?
NO
YES
BB1
Route Flow Through JJ2(I) Call MUSKIN
Add Discharges From JJ1(I) And JJ2(I)
Account For Lake Inflow To Channel Q11
Route Flow Through JJ2(I) Call MUSKIN
YES
I=NEL
NO
NO
T<NL3(J)?
YES
I = I+1
BB1
D
T = T+1
AA
BB

Figure 15 (continued)

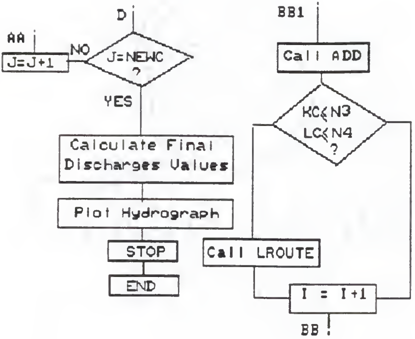


Figure 15 (continued)

consists of a starting time NF_3 and an ending time NL_3. There are NEWC independent events as previously described in the project. The program starts by looping the events. For each event J, the flow process is calculated over the time span (NF_3, NL_3) by incrementing the time by 1 hour. For each time value within the range (NF_3,NL_3), the flow calculations are made for all the NEL elements for 1 to NEL, following the elements classification by levels and classes. After all the time values in the range (NF_3,NL_3) are processed, control goes back to incrementing the event until the last event is covered.

3.2 Process Modeling

3.2.1 Flow Characterization

TROPICS handles four types of flow:

1) Overland flow or surface flow;
2) Groundwater flow (subsurface flow);
3) Channel flow; and
4) Lakes or reservoir flow.

3.2.1.1 Overland flow

Each element of the square grid system is an overland flow plane with a well-defined direction of steepest descent represented by the angle α (see previous sections). Like answers: Hydrologic model developed by Huggins and Monke in 1976. TROPICS has two different ways of handling overland flow; the first approach describes the flow in the element without channel segment and the second the flow in the element with channel. In the first case the flow is directed into the adjacent elements according to the flow decomposition scheme described in Chapter 2. In the second case the flow in the element is completely diverted into the channel segment crossing it. Figure 16 shows the hydrologic variables taken into account in the flow characterization process.

Et: is the water loss by evapotranspiration in the element;

i: is the incoming precipitation;

f: is the infiltration loss;

Qi: are the different inflow values from adjacent elements.

Qo: is the outflow from the element.

Overland Flow Routing

The continuity equation coupled with the Darcy-Weisbach equation is used to route the flow from an element to its adjacent (non-channel) element (or to channel segment when the element has a channel segment crossing it. The flow equation is written as follows:

Continuity equation.

$$\frac{ds}{dt} = Q_i - Q_o + A \cdot ie \qquad (18)$$

where: S = water storage in the element.

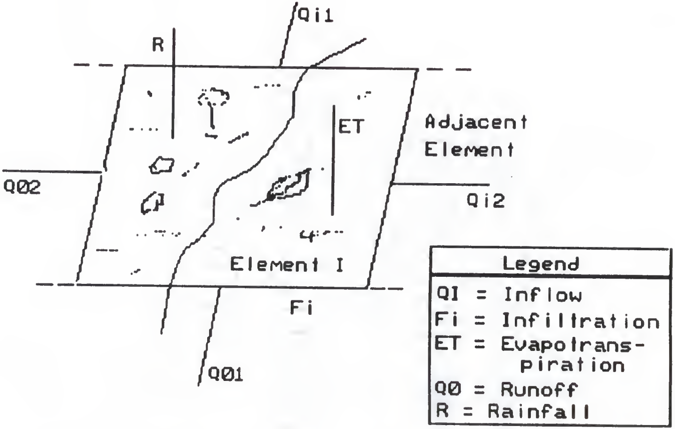


Figure 16. Conceptualization of the overland flow plane.

A = surface area of the element

$Q_i = \sum_{j=1}^{k} Q_{ij}$ is the sum of the k inflows into the element.

ie = effective precipitation in the element

(i.e. = i - f - ets).

$$Q_o = V_m \cdot A' \qquad (19)$$

where A' = a·y; y = flow depth; a = square element width

from the Darcy-Weisbach equation $\Delta H = f' \cdot \frac{Vm^2}{2g} \cdot \frac{\ell}{R}$

$$\Rightarrow v = \sqrt{\frac{2g}{f'o}} \cdot \sqrt{RS}\text{ ; for a plane flow}$$

$$y = R \Rightarrow vm = \sqrt{\frac{2g}{f'o}} \cdot y^{1/2} \cdot S^{1/2}$$

$$\text{Qo becomes } Qo = a \cdot y \cdot y^{1/2} \cdot S^{1/2} \cdot \sqrt{\frac{2g}{f'o}}$$

$$\Rightarrow$$

$$Qo = a \cdot S^{1/2} \cdot \sqrt{\frac{2g}{f'o}} \cdot y^{3/2};$$

where f'o is the equivalent friction factor introduced by the presence of the trees (see comments on how to obtain f'o). By replacing Qo by its value and setting the storage function to be S = A·y ($S = a^2 \cdot y$) in the continuity equation yields,

$$Qi - a \cdot \sqrt{S \cdot \frac{2g}{f'o}} \cdot y^{3/2} + A \cdot ie = A \cdot \frac{dy}{dt} \qquad (20)$$

To get the final form of this equation in order to solve it, it is necessary to determine the friction factor f'o.

The friction factor f' in the Darcy-Weisbach equation has been estimated by many investigators for open channel and close conduit conditions. Research has been done for canals with vegetated bottom where the vegetation is completely submerged and can bend so that the flow passes over it (Barnes, 1967; Henderson, 1966). It is later in the 70's that the friction factor was determined for the case where the vegetation does not bend and is an obstruction to the flow (Christensen, 1976). Another study on the same topic but this time applied to storm surge conditions was done by Christensen and Walton (1980). In the rain forest zone, trees are on the average very large and do not bend to flow. So the concept developed to determine f' for obstructed flow conditions seems appropriate for the rain forest zones. This concept, which will be explained shortly, is used in TROPICS to calculate f'o for flow routing purposes. The main idea in the obstruction to flow approach is to take into account the hydrodynamic drag on vegetation. Because whenever an object is placed in a moving fluid, it will experience a force in the direction of the fluid motion called the drag force. That force (F_s) is given by

$$FD = C_D \cdot \rho \cdot \frac{V^2}{2} \cdot A_1 \tag{21}$$

where C_D is the drag coefficient and A_1 is the projection of the area of the obstacle (trees here) in a plane perpendicular to the flow direction. Taking the drag into account, Christensen and Walton (1980) found the equation for the equivalent roughness factor f'o. This equation can be defined as follows:

$$f'o = f' + \sum_{i=1}^{nt} m_i \cdot y \cdot D_i \cdot C_D \tag{22}$$

where f'o = equivalent roughness factor.

f' = usual friction factor when the drag force is neglected.

m_i = number of trees of diameter D_i per unit area.

nt = number of different tree diameters/unit area.

C_D = drag coefficient.

y = flow depth.

Using Nikuradse's result (Nikuradse, 1933)

$$\frac{1}{4\sqrt{f'}} = 1.171 + \log \frac{R}{k}$$

and the modified velocity profile by Christensen (1972), i.e.

$$\frac{u}{uf} = 2.5 \, \mathrm{Ln}\left[10.94 \, \frac{y}{k} + 1\right]$$; f' is found by

$$f' = \frac{0.32}{\left[\mathrm{Ln}\left(\frac{10.94 \cdot y}{k} + 1\right)\right]^2}$$

$$\text{so } f_o'(y) = \frac{0.32}{\left[\mathrm{Ln}\left(\frac{10.94\ \cdot\ y}{k} + 1\right)\right]^2} + \sum_{i=1}^{k'} m_i \cdot y \cdot C_D \cdot D_i \quad (23)$$

Once M_i, C_D, k, and D_i are known f'o can be replaced by its value in the continuity equation.

The improved continuity equation becomes:

$$Q_i + A\cdot ie - \left(\sqrt{\frac{2qs}{\frac{0.32}{\mathrm{Ln}\left(\frac{10.94}{k}+1\right)^2} + C_D\left(\sum_{i=1}^{k'} mi\cdot Di\right)\cdot y}}\right)\cdot y^{3/2}\cdot a = A\cdot\frac{dy}{dt}$$

$$\Rightarrow \quad Qi + Aie - Qo(y) = A\,\frac{dy}{dt} \quad (24)$$

with

$$Qo(y) = \sqrt{\frac{2qsa^2}{\frac{0.32}{\left[\mathrm{Ln}\left(\frac{10.94}{k}\,y + 1\right)\right]^2} + C_D\left(\sum_{i=1}^{k'} miDi\right)\cdot y}}\cdot y^{3/2}$$

Solving (24) for y_2 using a finite difference scheme yields:

$$\frac{(Qi,2 + Qi,1)}{2} + A\cdot ie - \frac{1}{2}\left(Qo(y_1) + Qo(y_2)\right) = A\,\frac{y_2 - y_1}{\Delta t} \quad (25)$$

where Qi,1 = inflow in the element at the beginning of the time step Δt.

Qi,2 = inflow at time t + Δt.

y_1 = water depth at the beginning of time step Δt.

y_2 = unknown value = water depth at time t + Δt.

At the end of the time step Δt, i.e. at time t + Δt only the value of y_2 is unknown. So equation (25) is solved using an iterative method. TROPICS uses the Newton Raphson method to solve for y_2. The function used for the iterative method is:

$$F(y_2) = \left(\frac{Qi,1+Qi,2}{2}\right) + A \cdot ie - \frac{1}{2}(Qo(y_1)+Qo(y_2)) - A\frac{(y_2-y_1)}{\Delta t} = 0 \qquad (26)$$

The iterative scheme is the following:

$$y_2^{(n+1)} = y_2^{(n)} - \frac{F(1/2^{(n)})}{F'(1/2^{(n)})} \qquad (27)$$

n = nth iteration before convergence is achieved. Once the value of y_2 is found for the time step after the last iteration, Qo(y2) the flow at time t + Δt as:

$$Qo(y_2) = \sqrt{\frac{2gsa^2}{\frac{0.32}{\left(Ln\left(\frac{10.94}{k}\, y_2 + 1\right)\right)^2} + C_D\left(\sum_{i=1}^{k'} miDi\right) \cdot y_2}} \cdot y_2^{3/2} \qquad (28)$$

Qo(y2) or QoVa is the overland flow at the outlet of an element segment at time t + Δt.

Calculating the Drag Coefficient C_D and the number of trees/unit area mi

a) The drag coefficient C_D

1) First approach

Christensen and Wang (1983) have calculated the drag coefficient for flow through mangrove forests. They found a C_D value of 0.8. Several authors (Hsi and Nath, 1968; Hoerner, 1965; Petryk, 1969) found a drag coefficient of about 1.0 in heavily forested areas. From those findings a drag coefficient between 0.8 and 1.0 seems to be the values recommended by most investigators. These determinations of the drag coefficient were done in steady flow conditions with low roughness. For a more accurate determination of the drag an unsteady flow seems adequate (Gaston, 1979; Justesen, 1989, Sarpkaya, 1976).

2) Second approach

In this second approach to C_D determination one can assume unsteady flow conditions (Keulegan and Carpenter, 1958; Morison et al., 1950; Dean and Dalrymple, 1984) to account for a probable increase of the drag coefficient.

Keulegan and Carpenter (1958) were the first to investigate the incidence of unsteady flow conditions on the C_D value. For these conditions they found values of C_D close to 2.5. Later, Sarpkaya (1976), Gaston and Omart (1979) also found an increase in C_D values with roughness in unsteady flow conditions (see Table 1). Justesen, in experiments to calculate drag coefficients, found C_D values of about 2.3 for rough cylinders in oscillatory flow conditions.

So for tropical coastal areas such as Puerto Rico, the coastal African countries, etc. it seems advisable to spend more effort in determining C_D because of the devastating effect a high drag force on trees can create in storm surge conditions. The following is a summary of ways to determine the drag coefficient for unsteady flow in coastal zones.

Theory of shear stress and drag coefficient determination for unsteady flow conditions.

1) The total shear stress τ_o

The total sheer stress in the vicinity of a tree trunk obstructing the flow can be written as follows:

$$\tau_o = \tau_{viscosity} + \tau_{turbulence} + \tau_{drag} + T_{aC} \qquad (29)$$

The terms in equation (30) are defined below.

a) The total average shear stress τ_o

$\tau_o = \tau_b$ = total average bed shear stress introduced by the presence of trees in the bed area.

$\tau_o = \gamma RS$ where:

γ = specific weight; R = hydraulic radius;

S = friction slope with $S = (\Delta H/L)$

DH = total head loss

L = length of the flow path.

For the oscillatory flow conditions the Darcy-Weisbach equation can be written as:

$$\Delta H = f'e \cdot \frac{L}{R} \cdot \frac{|u(t)|\ u(t)}{2g} \qquad (30)$$

where: $u(t)$ = fluid velocity.

$f'e$ = is the equivalent friction factor introduced by the presence of tree trunks. So replacing ΔH by its expression in τ_o yields:

$$\tau_o = \rho \cdot f'e \cdot \frac{|u(t)|\ u(t)}{2}$$

ρ = fluid density.

b) The viscous shear stress $\tau_{viscosity}$ or τ_v

$$\tau_v = \mu \frac{du(t)}{dy} \cdot (1 - r) \qquad (31)$$

where: μ = the fluid dynamic viscosity

y = vertical direction

r = fraction of the total unit area occupied by obstructions (Fig. 12).

Assuming turbulent flow, $\tau_v = 0$ can be neglected in the expression of τ_o.

c) The turbulent shear stress $\tau_{turbulence}$ or τ_t

$$\tau_t = -\overline{\rho\ u'v'} \cdot (1 - r) \qquad (32)$$

u',v' = velocity fluctuations in x and y direction due to turbulence.

If we assume that $-\rho\ u'v' = \epsilon^2 \cdot \tau_t \qquad 0 < \epsilon < 1$

where τ_b is the bed shear stress, in absence of trees with:

$$\tau_b' = \rho \cdot f' \frac{|u(t)|\ u(t)}{2}$$

then:

$$\tau_t = \epsilon^2 \cdot \rho \cdot f' \cdot \frac{|u(t)|\ u(t)}{2}$$

taking $\epsilon^2 = 1$

$$\tau_2 = \rho \cdot f' \cdot \frac{|u(t)|\ u(t)}{2} \qquad (33)$$

f': the friction factor of the bed when there are no tree trunks

d) The drag and acceleration shear stresses: T_{drag} and τ_{ac}

τ_d and τ_{ac} can be derived from the wave force equation developed by Morison (1950). This equation is written as follows:

$$F = \frac{1}{2} C_D \cdot \rho \cdot A \cdot |u(t)| \cdot u(t) + C_M \cdot \rho \cdot Vol \cdot \frac{du(t)}{dr} \qquad (34)$$

where: F = wave force on a vertical cylinder or tree trunk (Fig. 2).

u(t) = oscillatory wave velocity

A = projected area/unit elevation of a cylindric tree trunk.

C_D = drag coefficient.

C_M = inertia coefficient.

Vol = volume of cylindric tree trunk

Comments on the inertia coefficient C_M

C_M can be written as $C_M = 1 + km$; where km is the added mass coefficient. The interpretation of the inertia coefficient is that the pressure gradient required to accelerate the fluid, exerts a "buoyancy" force on the cylindric tree trunk corresponding to the term 1 in the expression of C_M. An additional local pressure gradient depending on the shape of the object (here a cylinder) occurs to accelerate the neighboring fluid around the cylinder (Dean and Dalrymple, 1984). The drag shear stress τ_d and the acceleration shear stress is given τ_{ac} can be derived from equation (34) by introducing the term m, which is the number of trees/unit area.

1) The drag shear stress

By introducing the term m, the drag shear stress becomes:

$$\tau_d = mC_D \cdot \rho \cdot y \cdot D \cdot \frac{|u(t)|\ u(t)}{2} \qquad (35)$$

where: m = number of tree trunk/unit area.

y = flow depth.

D = tree trunk diameter

u(t) = fluid particle velocity

2) The added mass term or acceleration term

The added mass term is given by:

$$\tau_{ac} = m \cdot C_M \cdot \rho \cdot \text{Vol} \cdot \frac{du(t)}{dt} \qquad (36)$$

where $\frac{du(t)}{dt}$ is the acceleration term--by substituting all the shear term in the original equation

$$\rho\cdot f'e\cdot \frac{|u(t)|\ u(t)}{2} = \rho\cdot f'\cdot \frac{|u(t)|\ u(t)}{2}\cdot (1-r)$$

$$+\ \rho m C_D y\ \frac{|u(t)|\ u(t)}{2} + m\cdot C_M\cdot \rho\cdot \frac{\pi D^2}{4}\cdot y\cdot \frac{du(t)}{dt} \qquad (37)$$

One can measure u(t) and estimate f'e and calculate the Manning n with the equation

$$n = ((y^{1/3}\ \cdot\ f'e)/2g)^{1/2} \qquad (38)$$

Once C_D and C_M are known this would help get an idea of possible roughness in tropical coastal zones and determine its effect in flood situations

3) The drag coefficient

The general equation can be solved for f'e, e.g.

$$f'e_{t+dt} = \overset{(f't)}{f'(1-r)} + \overset{(f'd)}{m\ C_D\cdot y\cdot D} + \overset{(f'a)}{C_M\cdot m\cdot \frac{\pi D^2}{2}}\cdot y\cdot \frac{1}{(W(t+\Delta t))^2}\cdot\frac{\Delta u(t)}{\Delta t}$$

assuming $W(t+\Delta t) > 0$.

The following values were assigned to the various variables in equation (37):

$C_M = 2$; $C_D = 1.0$; $D = 0.20m$; $f' = 0.184$; $u(t) = 0.5\ m/s$;
$\Delta u(t) = 4/ms$; $y(t + \Delta t) = 1.00$; $\Delta t = 24$ hrs;
$m = 10$ trees/m^2.

The friction factor f'd was 2.00 while f't (turbulent friction factor) was 0.127 and f'a (the acceleration friction) was $6.5 \cdot 10^{-5}$. This shows the importance of the drag term. In another calculation, taking $C_D = 2.3$ (Justesen, 1989) and d = 4.0m (storm surge height of Hurricane Alicia occurred in Texas in 1983) and maintaining other parameters equal to their values previously assigned, f'e was found to be 18.53 giving an n value of 1.28 with equation. These results show that, theoretically, for large values of C_D in unsteady oscillatory flow conditions (storm surge), Manning n can be very high and the wave forces on tree trunks also high.

Proposed method to determine C_D in obstructed flow

From the work done by previous investigators (Keulegan, 1958; Sarpkaya, 1979; Justesen, 1989), the following method is suggested to determine C_D:

1) set up an experiment to measure F(t) at each wave cycle in a wave tank.
2) measure velocities for different time steps or use a wave theory to measure wave velocities.
3) Hold the Reynolds number Re to 10^5; take the Kc (Keulegan-Carpenter number is $\frac{U_m \cdot a}{T}$ where U_m = average wave velocity; a = amplitude of the wave and T = wave period) to be approximately between 12 and 15. Take the roughness ratio k/D to be close to 0.02.

(These values are suggested because of the findings of Justesen (1989) and Sarpkaya (1979).

4) Then use the least square method proposed by Dean and Aagaard (1970) to calculate C_D and C_M.

For the user of TROPICS values of C_D close to 1.5 can be used to account for the unsteady flow conditions if extreme flow conditions are suspected in the tropical rain forest. TROPICS calculates the flow reynold number based on trees diameters. When the Reynolds number is less than 10^5, the drag coefficient takes the value of 1.5. When the Reynolds number is greater than 10^5, $C_D = 0.3$. This sets the limit between laminar and turbulent boundary layers.

b) The number of trees per unit area--(mi)

The number (mi) of trees of diameter Di in a given forest is very hard to find. The number mi is usually found by counting the number of trees of diameter Di in several lots of a given size and extrapolating the values found to larger areas. An equation often used by foresters to find the number of trees per unit area is the following:

$$N = \frac{4G}{\pi dg^2} \tag{39}$$

where: N = number of trees per unit area

dg = mean diameter of the tree (dg = Di)

G = basal area per hectare.

G is found by adding the surface of cross sectional areas of all trees of a given diameter dg (dg is taken at breast height), dividing by the surface of the lot where the sampling was made and converting to $\frac{m^2}{ha}$.

$$G = \frac{\Sigma \text{ (cross sectional area of trees of diameter dg)}}{\text{Total area of sample plot}} \tag{40}$$

Once G is found N can easily be calculated using the expression of N as a function of G. The equation $N = \frac{4G}{\pi dg^2}$ was proposed by the Commonwealth Forestry Association (1974). The graph (Fig. 17) was proposed by the association. It allows a quick determination of N when G is known.

3.2.1.2 Groundwater flow

a) General description

The groundwater estimation in TROPICS is in a way similar to the groundwater conceptualization in the SWMM model. In TROPICS the soil profile is subdivided into two zones--an upper layer where the trees of the tropical rain forest develop and a lower zone. The lower zone is considered generally saturated compared to the upper zone. However, in the humid tropical rain forest zones with heavy rainfall that upper zone can be rapidly saturated, and giving way to the occurrence of runoff. The most important parameter in the groundwater determination in TROPICS is the

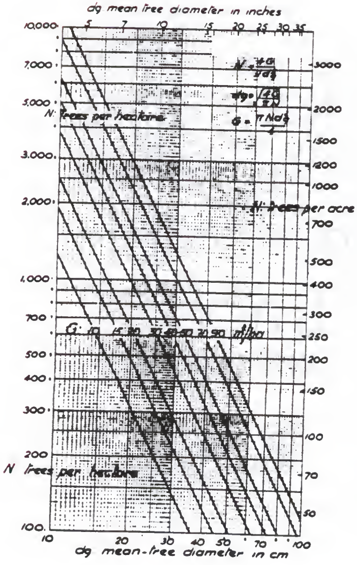


Figure 17. Graph to determine the number of trees/unit area. (Adapted from the Commonwealth Forestry Association, 1981)

groundwater release term called GWR. It represents the portion of the flow emerging to streams lying within the watershed. So the groundwater release is taken into account only in elements of the basin having one or two channel segments crossing them. All the groundwater released from an element is directed to the channel segments in the element at each simulation time step according to the element shadow concept underlined by Beasly (1976). There are many variables involved in determining the term GWR or its average $\overline{GWR}$ over the time step Δt these parameters most of them shown in Figure 18 are defined as follows:

Dmax = depth over which groundwater can be released from an element. When the element has a channel or two channel segments: Dmax = Htot - H_c.

Htot = average elevation of the element surface from a known reference point.

H_c = elevation of channel bottom.

Etl = lower zone transportation in the soil profile.

Etu = upper zone transpiration.

FIL = net infiltration rate at the soil surface.

PERC = flow from the upper zone to the lower zone.

RMAXZD = maximum root zone depth measured from element surface.

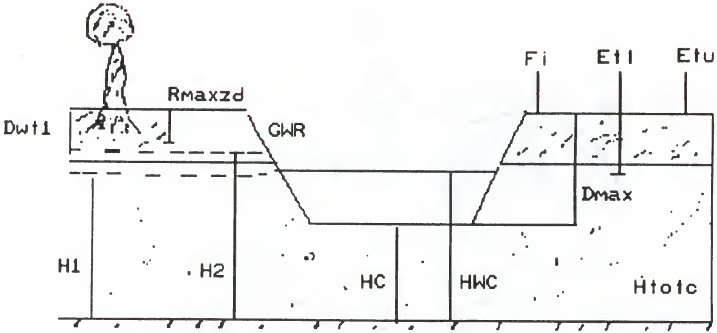


Figure 18. Conceptualization of groundwater flow.

H_1 = water table elevation at the beginning of time step Δt.

H_2 = water table elevation at the end of time step Δt.

GWR = groundwater release from the soil profile to the channel(s) in the element.

$\overline{GWR}$ = average groundwater release over Δt.

HWC = water table level in the channel.

DWT = water table depth in the element.

POR = porosity of soil.

b) Estimation of groundwater flow parameter

In order to determine the amount of water released from the soil profile over a discrete time interval Δt, it is necessary to make a water balance in the soil profile according to the continuity equation

$\frac{ds}{dt} = I - 0$ or in finite difference form

$$\frac{\Delta s}{\Delta t} = I - 0 \qquad (41)$$

where: Δs = change in storage over Δt

Δt = time increment of calculations

I = input to the soil profile

0 = output from the soil profile

1) Upper zone water balance

The application of the continuity equation in the upper zone of the soil profile (Huber et al., 1987) yields:

$$\theta_2 = \{(fe-perc)\cdot\Delta t\cdot imp+(H_1-H_2)\cdot\theta_2+\theta_1\cdot dwt_1\}/(H_{tot}-H_2) \qquad (42)$$

where: θ_2 = soil water content at the end of the time step Δt

θ_1 = beginning of time step water content.

fe = f (actual infiltration) - etu (upper zone transpiration)

fe = effective infiltration

fe = 0 for impervious areas

imp = imperviousness percentage in the element.

Equation (42) can be simplified by putting dwt1 = Htot - H1; then we obtain:

$$\theta_2 = \{(fe-perc)\cdot\Delta t\cdot imp/dwt1\} + \theta_1 \qquad (43)$$

2) In the lower zone

Using the continuity concept in the lower zone (saturated zone), the water table elevation H_2 at the end of time step Δt is:

$$H_2 = \frac{(Perc - Etl)\cdot Imp - \overline{GWR})\cdot\Delta t}{(POR + \theta_1 - 2\theta_2)} + H_1 \qquad (44)$$

The variables here have previously been defined

$$Etl = Ka \cdot \left(\frac{MAXRZD - \left[(Htot - \left[\frac{H_1+H_2}{2}\right]\right]}{MAXRZD}\right) \cdot Eo \qquad (45)$$

and

$$GWR = COEFF\ \frac{\left[Dmax - \left[Htot - \left[\frac{H_1+H_2}{2}\right]\right]\right]}{Dmax}. \qquad (46)$$

where Eo is the evapotranspiration value. By replacing Etl, perc, and GWR by their values as a function of H_2 Equation (44) can be solved interactively. That equation is the one used for the H_2 calculation in the computer program.

COEFF = Groundwater coefficient.

3) Calculating the percolation (perc)

Percolation is one of the most important parameters to be determined in the Groundwater routine. Perc is defined by

$$\text{perc} = -k(\theta)\,\frac{dh}{dz} \qquad (47)$$

where: $k(\theta)$ = hydraulic conductivity.

h = hydraulic potential; h = z + phi

with phi = soil water tension head

z = elevation.

The percolation equation was investigated in the SWMM model (Huber et al., 1987) and its final form is as follows:

$$\text{Perc} = \text{KSAT}\cdot\text{EXP}[(\theta\text{-por})\cdot\text{HCO}]\cdot(1+\text{Pco}\cdot(\theta\text{-Fc})/(\text{Dtw}) \qquad (48)$$

where: Ks = hydraulic conductivity at saturation.

HCO = constant calibration parameter.

$$\text{PCO} = \frac{\Delta\text{PHi}}{\Delta\theta};\ \text{obtained from } \frac{d\text{Phi}}{dt} = \frac{d\text{Phi}}{d\theta} \times \frac{d\theta}{dz}$$

So PCO can be obtained from curves $\theta = f(\text{Phi})$

DTW1 = beginning of time step water table depth

Fc = field capacity

4) Iterative procedure to calculate GWR (the groundwater release term

1. Solve for θ_2 in equation (43).
2. Replace θ_2 by its values found in (1) with equation (44). Solve for H_2 using the Newton Raphson iterative method.
3. Calculate $\overline{GWR}$ by replacing H_2 by its calculated value in (46).
4. One can also estimate the upper zone evapotranspiration Etu and the lower zone Et by substituting the values previously calculated in Equation (45) and in the expression:

$$Etu = \left(\frac{\theta_2 - Fc}{Fc - Wp}\right) \cdot Eo \qquad (49)$$

Determination of parameters for groundwater flow

a) The coefficient COEFF.

$$GWR = COEFF \cdot \left(\frac{Dmax - dwt}{Dmax}\right) \cdot \qquad (50)$$

COEFF can be determined by local groundwater flow measurement or by plotting a yearly hydrograph of the zone and obtained COEFF by baseflow separation techniques. The potential groundwater release can be taken to be the maximum baseflow observed in.

b) Dmax = maximum depth of water release is variable for different soil. Should be locally estimated.

c) MAXRZD = maximum root zone depth. Depends on soil characteristics. Can vary between 2 and 8 meters in the tropical rain forest.

d) Other coefficients ks, etc. are obtained from soil characteristic curves.

Determination of Muskingum coefficients x and k

a) The x factor. The value of x varies between 0. and 0.5 $k = 0 \Rightarrow S = KO$ gives the linear reservoir case. $k = 0.5 \Rightarrow S = 0.5k\ (I - 0)$ which is a pure translation case. TROPICS uses $x = 0.25$ which is an intermediate case between the two extremes. (Great accuracy in determining x may not be necessary because the results are relatively insensitive to the value of that parameter.)

b) The k factor. k is the time factor. It is usually taken to be equal to the travel time of a flood through a river reach. The travel time T_t is equal to

Δx = reach length

C = wave celerity

for a channel reach 1 and flow in the rough range:

$C = m \cdot V_m$ (Bedient and Huber, 1988)

$V_m = \frac{Q}{A}$ = average flow velocity in the channel

$m = \text{constant} = \frac{5}{3}$ (turbulent flow).

$$\Rightarrow \quad k = \frac{l}{m \cdot V_m} = \frac{l \cdot A}{Q \cdot m}$$

$$\Rightarrow \quad k = \frac{3lA}{5Q} \qquad (51)$$

For a given k value it was proven that there is stability if $2KX \leq \Delta t \leq 2k(1-x)$.

Estimation of Initial Channel Input Data

The parameters necessary for the channel flow routing are: RLEN (channel length), HTOTC (elevation of surface of the soil near the channel). XX (Muskingum coefficient already determined), SLOP is the channel slope, Vm (the average water velocity in the channel) HWC (the water level elevation in the channel), yyo (the initial water depth), QQo (the channel initial discharge) and Hc (the channel bottom elevation). The first four parameters RLEN, HTOTC, XX and slop should be obtained from a topographic map or archives on the channel of the location.

The other variables, Vm, yyo, QQo, HWC, HC, can be obtained by reports of channel characteristics. If they can be found, Tropics can estimate those variables with subroutine Chanip in the model. The procedure to find those parameters can be described as follows.

The first step is to obtain enough data on the region to find a formula of the form

$$Q_R = \alpha A_R^{\beta} \quad (*)$$

α and β can be obtained by a non-linear regressional on QR (discharge at the River outlet in m^3s^{-1}) and A_R (the basin area to produce Q_R in km^2) when a representable size NREG (Q_R, A_R) values are available. Once equation (*) is determined for the region, the basin of study is divided into as many subbasins as is needed to estimate the initial flow out of every channel segment.

The next step is to use the formulas of Lacey (1930) or those of Stevens and Nordin (1987, 1990) which are the revised form of the original Lacey's Formulas. The formulas of Nordin and Stevens (1990) are used in TROPICS. These relationships relate the characteristics such as the wetted perimeter (P), the hydraulic radius (R), the channel slope (S), the mean velocity (V_m) and the channel cross sectional area (A) to power functions of the discharge Q in the channels, and the sediment concentration (C_s) is known in the channel. The formulas in SI units are given as follows:

$$P = 4.84\ Q^{1/2}$$

$$R = 2.11\left(\frac{Q}{C_s}\right)^{1/3}$$

$$S = \frac{C_s^{5/3}}{6.05\cdot 10^6\ Q^{7/6}}$$

$$V_m = 0.0983\ Q^{7/6} C_s^{7/3}$$

$$A = 10.2 \frac{Q^{5/6}}{C_s^{1/3}}$$

In these formulas Q is (m^3s^{-1}), S dimensionless, A is (m^2), V_m is ms^{-1}), R and P are in meters and C^s is in (mg/ℓ). Subroutine CHANIP calculates the initial channel parameters using the formulas described above. In addition to the equation listed above, $Zf = 1/3\ 28 + 0.25 \cdot R$ gives an estimate of the free board in the channel.

3.2.1.3 Channel flow routine

The channel flow routing in TROPICS is calculated using the Muskingum hydrologic routing method. This method models the storage volume of flooding in a river channel by a combination of wedge and prism storage.

During the advance of a flood wave, inflow exceeds outflow, producing a wedge of storage. During the recession, outflow exceeds inflow, resulting in a negative wedge. In addition, there is a prism of storage which is formed by a volume of a constant cross section along the length of prismatic channel. The method assumes that the cross-sectional area of the flood flow is directly proportional to the discharge at the section, the volume of the prism is equal to KQ where K is a proportionality coefficient, and the wedge storage volume is equal to

KX(I-Q), where X is a weighing factor which values lie in the range $0 \le X \le 0.5$. So the total storage is given by:

$$S = KQ + KX(I - Q) \tag{52}$$

and represent the storage function for the Muskingum method. The routing equation of the Muskingum method is derived from the storage function above. It is obtained as follows: The change in storage over time interval Δt is:

$$S_{j+1} = S_j = K\{[XI_{j+1}+(1-X)Q_{j+1}]-[XI_j+(1-x)Q_j]\} \tag{53}$$

where

$$S_j = K[XI_j+(1-X)Q_j] \tag{54}$$

and

$$S_{j+1} = K[XI_{j+1}+(1-X)Q_j+1] \tag{55}$$

The same change in storage can also be expressed as

$$S_{j+1} - S_j = \frac{I_j+I_{j+1}}{2} \cdot \Delta t - \frac{Q_j+Q_{j+1}}{2} \cdot \Delta t$$

by equating both expressions of the change of storage, the well-known expression of the Muskingum equation is obtained:

$$Q_{j+1} = C_0I_{j+1} + C_1I_j + C_2Q_j \tag{56}$$

where

$$C_0 = \frac{-KX + 0.5\Delta t}{D} \tag{57}$$

$$C_1 = \frac{KX + 0.5\Delta t}{D} \tag{58}$$

$$C_2 = \frac{K - KX + 0.5\Delta t}{D} \tag{59}$$

with

$$D = K - KX + 0.5\Delta t \qquad (60)$$

with

$$C_0 + C_1 + C_2 = 1.0$$

The expression of the Muskingum taking into account the notations in TROPICS (Fig. 19) is as follows:

$$QCO,k(t+\Delta t) = CO \cdot QCI,k(t+\Delta t)+C_1 \cdot QCI,k(t)+C_2 \cdot QCO,k(t) \qquad (61)$$

where

$QCO,k(t+\Delta t)$ = Outflow at the downstream end of the channel segment k at time t + Δt.

$QCI,k(t+\Delta t)$ = Inflow at time t + Δt into the channel segment k.

QCI,k(t) and QCO,k(t): are the same parameters as the one described above but occurring at time t.

CO, C1, C2 remains the same.

A channel segment JJ(I) receives its inflows from its adjacent segment(s), i.e. the outflow from the adjacent element is the inflow to the present channel segment. The outflow, $Q_{out,k-1}$, from the adjacent channel segment to JJ(I) is the sum of overland flow, Qova, groundwater flow GRW and previous channel discharge, i.e. if k is the assigned sequential number to the present channel and k-1 is the number assigned to the adjacent channel, the following equalities can be written:

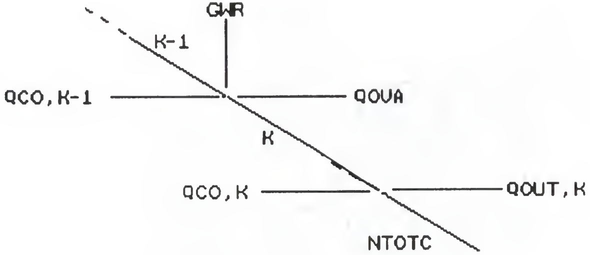


Figure 19. Inflows and outflows of a channel segment k.

Qout, k-1 = QCI,k

where Qout, k-1 = outflow from adjacent segment k-1 at time t and QCI,k = inflow to present channel segment k,Qout, k-1 = Qova + GRW + Qco,k-1. The pure channel outflow Qco,k at the outlet of channel k is obtained by routing the flow through that element using the Muskingum flow routing scheme described previously. The following is an example of how channel flow types are handled in TROPICS. The inflows and outflows are calculated according to the 4 criteria described below:

1) Boundary channel segment (no adjacent channel segment)

Inflow = QCI(n,JJ(I)) = Qo

Outflow = Qout(n,JJ(I)) = Qco(n,JJ(I))+Qova(n,I)+GWR(n,JJ(I))

where: n = time in hour

Qo = initial channel discharge

Qco(n,JJ(I)) = pure channel outflow of the channel of the element channel segment JJ(I)

Qova(n,I) = overland flow generated within element I containing the channel segment JJ(I)

GWR(n,(JJ(I)) = groundwater released to the channel

2) Channel with only one adjacent segment with no lake inflow

Inflow: QCI(n,JJ(I)) = QCO(n,NCH(JJ(I))) = Qout(n,NCH(JJ(I))

Outflow: Qout(n,JJ(I)) = QCO(n,JJ(I))+Qova(n,I)+GWR(n,JJ(I))

The notations are the same as the previous case.

3) Channel receiving flow from the lake in the basin (only 1 such channel exists)

Inflow: QCI(n,JJ(I)) = QOL(n)

where

QoL(n): is the outflow from the lake at time n

Outflow: Qout(n,JJ(I)) = QCO(n,JJ(I))+Qova(n,I)+GWR(n,JJ(I))

4) Channel JJ(I) with two adjacent segments

Inflow: QCI(n,JJ(I)) = QCO(n,NSC(JJ(I),1))+QCO(n,NSC(JJ(I),2)
+Qova(n,Iprev(I))+GWR(n,NSC(JJ(I),1))
+GWR(n,NSC(JJ(I),2))

where

QCO(n,nsc(JJ(I),1)): is the outflow out of the first channel segment adjacent to JJ(I) at time n

QCO(n,nsc(JJ(I),2)): is the outflow out of the second channel segment adjacent to JJ(I) at time n

Qova(n,Iprev(I)) is the overland flow from element Iprev(I), i.e. the element containing 2 channel segment adjacent to JJ(I)

GWR(n,NSC(JJ(I),1)): is the groundwater release from the first adjacent channel at time n

GWR(n,NSC(JJ(I),2)): is the groundwater release from the second adjacent channel segment.

For all these cases the outflow is obtained by using the Muskingum routing scheme described previously.

3.2.1.4 Flow from lakes and reservoirs

The flow from lakes and reservoirs is routed using the non-linear reservoir routing method.

$$A_l \cdot ie + GWR + Q_{0,c} + Qover - Qo = A_l \cdot \frac{dh}{dt} \tag{62}$$

Qover = overland flow contribution to the lake

Qo,c = channel contribution

GWR = groundwater release to the lake

Al•ie = flow direct by input to the lake

Qo = outflow from the element.

The Manning equation is chosen to calculate the outflow from the lake.

$$Qo = a \cdot \frac{1 \cdot 49}{n} \cdot h^{5/3} \cdot S^{1/2} \text{ or } Qo = a \cdot \frac{1}{n} h^{5/3} \cdot S^{1/2}$$

Therefore the finite difference scheme applied to the lake gives

$$\frac{h2-h1}{\Delta t} = \overline{Qi'} - \frac{a}{Al} \cdot \frac{1}{n}\left(\frac{h1+h2}{2}\right)^{5/3} \cdot S^{1/2} \tag{63}$$

$\overline{Qi'}$ = average of the inflows coming to the lake.

A Newton-Raphson method is used to calculate h2; then the Manning equation allows the computation of the reservoir or lake outflow. All the inflow components are computed using the different subroutine LROUTE of the model.

3.2.2 Description of Hydrologic Processes In TROPICS

3.2.2.1 Precipitation:

Hourly precipitation data over a week period is input to the model (TROPICS). Variable sources of precipitation exist throughout the world (NOAA, WMO, U.S.G.S., SCS, etc.). TROPICS is more of a forecasting model, i.e. most of the variables are predicted from the precipitation data. So the key in working with TROPICS is to have a good precipitation data set. For the example studied in this project the precipitation data were obtained from NOAA for a tropical rain forest in the northeastern part of Puerto Rico called Fajardo. The basin of about 69 km^2 has stream flow records. The existence of the flow record makes it possible to compare the natural measured outflow hydrograph and the predicted one obtained using TROPICS. This area, like most tropical rain forest zones, is very humid; monthly precipitation can reach up to 30 inches in the pico del Este area.

3.2.2.2 Interception

The interception scheme proposed by Fleming (1975) is used to simulate the interception process in TROPICS. The conceptualization of the procedure is described on Figure 20. In this approach, the input to the interception storage is precipitation, and the output is a continuous evaporation

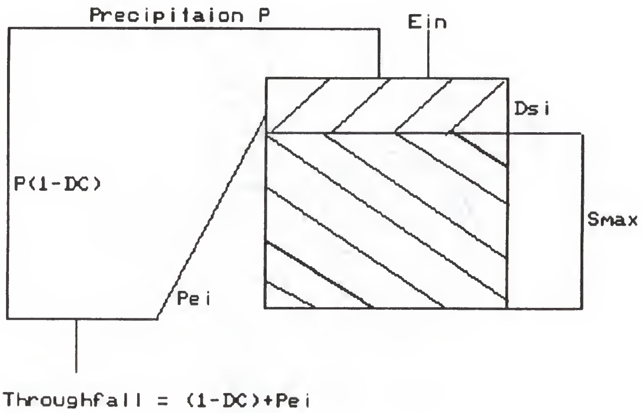


Figure 20. Conceptualization of interception in TROPICS.

and moisture in excess of the interception capacity. The change in interception storage is

$$\Delta Si = P \cdot DC - Ein \quad (64)$$

where Δsi = change in interception storage when the maximum interception rate is exceeded (cm)

P = precipitation input in the area of study (cm)

DC = canopy density in the element--unitless

Ein = evaporation from interception storage (cm)

The throughfall Tg(t) at the end of the time step t

$$Tg(t) = Si(t-1) + \Delta si(t)\Delta t - Smax + P(1-Dc) \cdot DT \quad (65)$$

where Smax = maximum interception depth

Si(t-1) = interception storage at time t-1

$\Delta Si(t)$ = change in interception storage

DT = time increment

P(1-DC) = direct throughfall (see Fig. 20).

The throughfall (Tg(t) or THRG(t) in the program is not allowed to be less than 0.0. If it is the case, then the Tg(t) value is set to zero. In the model, Tg(t) is calculated for each end of time step and becomes the rainfall rate for the remaining subroutines of the model.

Estimation of Smax and DC

a) Dc: canopy density.

$$Dc = \frac{Av}{Al} \quad (66)$$

Av = horizontal projection of surface area of intercepting vegetation

Al = surface of land containing Av.

In forestry the planimetric or horizontal projection of the tree crown is assumed to be circular. A circle of equivalent area is estimated and the projected diameter is determined. Few studies are found in literature which describe the computation of Dc. Av can be determined using the following equation developed for different rain forest zones (Perez, 1970):

$$\phi = \alpha d_s^{\beta} \tag{67}$$

where ϕ = projected or equivalent crown diameter

ds = tree stem diameter

α, β = constants

then $Av = \pi/4 \cdot \phi^2 = \pi/4 \cdot \alpha^2 \cdot d_s^{(2\beta)}$

if mi is the number of trees of diameter d_{si} per unit area,

then $Av = \sum_{i=1}^{n} Avi \cdot mi$

$Avi = \pi/4\ \alpha^2 (d_{si})^{2\beta}$ ⇒ A new relationship was therefore developed which gives the Dc value

$$Dc = \frac{\pi/4\ \Sigma\ mi\ \phi i^2}{Al} = \frac{\pi}{4 \cdot Al} \cdot \alpha^2 \cdot \Sigma\ mi \cdot (d_{si})^{2\beta}$$

so the equation used to calculate the tree canopy density in TROPICS is

$$Dc = \frac{\alpha^2\pi}{4Al} \cdot \sum_{i=1}^{n} mi \cdot (dsi)^{2\beta} \qquad (68)$$

n = total number of trees of different diameter class (number of tree classes of ϕ in the area). The most common tree diameters dsi in rain forest zones are:

dsi = 10, 20, 30, 40, 50, 60, 70, 80, 90, 100.

In some areas diameters of about 200 cm can be found (Perez et al., 1970). Values of α and β were found for different rain forest zones (Perez et al., 1970).

$$\underline{\text{Puerto Rican Rain Forests}} \rightarrow \begin{cases} \alpha = 0.6353 \\ \beta = 0.8392 \end{cases}$$

$$\underline{\text{Dominican Rain Forests}} \rightarrow \begin{cases} \alpha = 0.3552 \\ \beta = 0.9112 \end{cases}$$

$$\underline{\text{Monsoon Rain Forests}} \rightarrow \begin{cases} \alpha = 0.6341 \\ \beta = 0.6711 \end{cases}$$

so an average tropical rain forest value of $\alpha = \bar{\alpha} = 0.5415$ and $\beta = \bar{\beta} = 0.8072$. α and β are unitless.

a) Smax = maximum interception storage value

The range of Smax for rain forest is 1 to 5mm. So a maximum interception storage of Smax = .3mm can be used in TROPICS for a trial. The actual value of Simax should be used for the site of study when it is available.

3.2.2.3 Infiltration

There is a large number of infiltration equations in hydrology. These equations can be classified in two main categories:

1) The empirical equations which are defined by fitted parameters; and

2) The physically based ones derived from flow theory in porous media.

TROPICS uses the second type of equation to model infiltration. It uses the modified form of the Green-Ampt equation developed by Mein and Larson (1971). The GAML (Mein and Larson version of the Green-Ampt equation) was derived from the Richards equation (Richards, 1931):

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left\{(K(\theta)\ \frac{\partial\psi}{\partial z}\right\} - \frac{\partial K(\theta)}{\partial z} \qquad (69)$$

where θ = soil water content,

$k(\theta)$ = the hydraulic conductivity as a function of the water content

z = land elevation

ψ = soil water potential

This equation was chosen because of the following advantages:

1) It utilizes soil characteristics that can be measured in the laboratory from soil samples (hydraulic conductivity and saturation moisture content).

2) It has no fitted parameters. Infiltration tests are not required. No calibration is necessary. The equation is therefore suitable for areas where field data are rare, limited, or very difficult to obtain like in most tropical developing countries of the world.

3) It has given satisfactory results under field conditions (Slack and Larson, 1981).

The GAML is defined in two stages:

1st stage: The time to surface ponding is found using

$$tp = Fp/i \tag{70}$$

$$\text{where } Fp = \frac{Sav \cdot DEFC}{i/kfs - 1} \tag{71}$$

The parameters in Fp are:

Fp = cumulative volume of infiltration at the instant of surface ponding

i = rainfall intensity

DEFC = soil moisture deficit = $(\theta s \; \theta i)*$ Sav (θs = moisture content at soil saturation and θi = initial soil moisture content).

Kfs = saturated hydraulic conductivity.

Sav = average suction at the wetting front.

2nd stage: After ponding the infiltration is modeled by the following scheme:

$$Ks(t-tp+tp') = F-DEFC \cdot Sav \cdot Ln\left(1 + \frac{F}{DEFC \cdot Sav}\right) \tag{72}$$

where tp is the same as defined above.

t'p = equivalent time to infiltrate the volume Fp under ponded surface conditions.

F is calculated iteratively using equation (74) for a given time step. Once F is known, the infiltration rate is calculated using

$$f = ks \cdot \left(1 + \frac{DEFC \cdot Sav}{F}\right) \qquad (73)$$

In summary TROPICS handles infiltration as follows:

a) if $F < Fs = Fp$ (with $Fs = \frac{Sav \cdot DEFC}{i/ks - 1}$ for $i > ks$)
(Fs saturation infiltration volume)

then $i < fp$ and $f = i$ (Fs is not defined for $i \le ks$)

b) If $F = Fs$, then $i = fp$ and $f = fp = i$.

c) If $F > Fs$, then $i > fp$ and $f = fp = ks\left(1 + \frac{DEFC \cdot Sav}{F}\right)$

Data Obtention

a) Sav: Average suction at the wetting front has been defined for soil types (see Table 2).

b) Ks, θs, θi are determined from soil data. Table 2 also gives values of different parameters.

3.2.2.4 Depression storage

When rainfall occurs at an intensity greater than the infiltration capacity, surface depressions start to fill.

Table 2. Green and Ampt parameters according to soil texture, classes and horizons.

Soil texture class (1)	Horizon (2)	Sample size (3)	Total porosity, ϕ, in cubic centimeters per cubic centimeters (4)	Effective porosity, θ_e, in cubic centimeters per cubic centimeters (5)	Wetted front capillary pressure, ψ_f[a] in centimeters (6)	Hydraulic conductivity, K[b] in centimeters per hour (7)
Sand[c]		762	0.437 (0.374–0.500)[d]	0.417 (0.354–0.480)	4.95 (0.97–25.36)	11.78
	A	370	0.452 (0.396–0.508)	0.431 (0.375–0.487)	5.34 (1.24–23.06)	
	B	185	0.440 (0.385–0.495)	0.421 (0.365–0.477)	6.38 (1.31–31.06)	
	C	127	0.424 (0.385–0.463)	0.408 (0.365–0.451)	2.07 (0.32–13.26)	
Loamy sand		338	0.437 (0.363–0.506)	0.401 (0.329–0.473)	6.13 (1.35–27.94)	2.99
	A	110	0.457 (0.385–0.529)	0.424 (0.347–0.501)	6.01 (1.58–22.87)	
	B	49	0.447 (0.379–0.515)	0.412 (0.334–0.490)	4.21 (1.03–17.24)	
	C	36	0.424 (0.372–0.476)	0.385 (0.323–0.447)	5.16 (0.76–34.85)	
Sandy loam		666	0.453 (0.351–0.555)	0.412 (0.283–0.541)	11.01 (2.67–45.47)	1.09
	A	119	0.505 (0.399–0.611)	0.469 (0.330–0.608)	15.24 (5.56–41.76)	
	B	219	0.466 (0.352–0.580)	0.428 (0.271–0.585)	8.89 (2.02–39.06)	
	C	66	0.418 (0.352–0.484)	0.389 (0.310–0.468)	6.79 (1.16–39.65)	
Loam		383	0.463 (0.375–0.551)	0.434 (0.334–0.534)	8.89 (1.33–59.38)	0.34
	A	76	0.512 (0.427–0.597)	0.476 (0.376–0.576)	10.01 (2.14–46.81)	
	B	67	0.512 (0.408–0.616)	0.498 (0.382–0.614)	6.40 (1.01–40.49)	
	C	47	0.412 (0.350–0.474)	0.382 (0.305–0.459)	9.27 (0.87–99.29)	
Silt loam		1,206	0.501 (0.420–0.582)	0.486 (0.394–0.578)	16.68 (2.92–95.39)	0.65
	A	361	0.527 (0.444–0.610)	0.514 (0.425–0.603)	10.91 (1.89–63.05)	
	B	267	0.533 (0.430–0.636)	0.515 (0.387–0.643)	7.21 (0.86–60.82)	
	C	73	0.470 (0.409–0.531)	0.460 (0.396–0.524)	12.62 (3.94–40.45)	
Sandy clay loam		498	0.398 (0.332–0.464)	0.330 (0.235–0.425)	21.85 (4.42–108.0)	0.15
	A	—[e]	— —	— —	— —	
	B	198	0.393 (0.310–0.476)	0.330 (0.223–0.437)	26.10 (4.79–142.30)	
	C	52	0.407 (0.359–0.455)	0.332 (0.251–0.413)	23.90 (5.51–103.75)	
Clay loam		366	0.464 (0.409–0.519)	0.309 (0.279–0.501)	20.88 (4.79–91.10)	0.10
	A	28	0.497 (0.434–0.560)	0.430 (0.328–0.532)	27.00 (6.13–118.9)	
	B	99	0.451 (0.401–0.501)	0.397 (0.228–0.530)	18.52 (4.36–78.73)	
	C	55	0.452 (0.412–0.492)	0.400 (0.320–0.480)	15.21 (3.79–61.01)	
Silty clay loam		689	0.471 (0.418–0.524)	0.432 (0.347–0.517)	27.30 (5.67–131.50)	0.10
	A	65	0.509 (0.449–0.569)	0.477 (0.410–0.544)	13.97 (4.20–46.53)	
	B	191	0.469 (0.423–0.515)	0.441 (0.374–0.508)	18.56 (4.08–84.44)	
	C	39	0.475 (0.436–0.514)	0.451 (0.386–0.516)	21.54 (4.56–101.7)	
Sandy clay		45	0.430 (0.370–0.490)	0.321 (0.207–0.435)	23.90 (4.08–140.2)	0.06
	A	—	— —	— —	— —	
	B	23	0.435 (0.371–0.499)	0.335 (0.220–0.450)	36.74 (8.33–162.1)	
	C	—	— —	— —	— —	
Silty clay		127	0.479 (0.425–0.533)	0.423 (0.334–0.512)	29.22 (6.13–139.4)	0.05
	A	—	— —	— —	— —	
	B	36	0.476 (0.445–0.507)	0.424 (0.345–0.503)	30.66 (7.15–131.5)	
	C	21	0.464 (0.430–0.498)	0.416 (0.346–0.486)	45.65 (18.27–114.1)	
Clay		291	0.475 (0.427–0.523)	0.385 (0.269–0.501)	31.63 (6.39–156.5)	0.03
	A	—	— —	— —	— —	
	B	70	0.470 (0.426–0.514)	0.412 (0.309–0.515)	27.72 (6.21–123.7)	
	C	23	0.483 (0.441–0.525)	0.419 (0.294–0.544)	54.65 (10.59–282.0)	

[a] Antilog of the log mean and standard deviation.
[b] Values for Rawls et al. (13)
[c] Values for the texture class
[d] Numbers in ( ) ± one standard deviation
[e] Insufficient sample to determine parameter.

Source: used with permission Rawls et al. 1983.

The smallest ones are filled first followed by larger ones and local overland flow begins. Large depressions will continue to be filled until the basin scale runoff begins.

Skaggs (1974) showed that the magnitude of the surface depression storage affects the response of the water table to a given storm event. Soil depression storage depends on the type of the soil. It was reported (Skaggs, 1978) that soil poorly drained could be flooded for about 45 hours, while well-drained soils quickly lose their water by infiltration. TROPICS handles depression storage with the generalized equation proposed by Linsley et al. (1949):

$$Vd = S_d\left(1 - \left(e^{-k \cdot ie}\right)\right) \qquad (74)$$

where Vd = volume in storage at a given time.

S_d = maximum storage capacity of the depression storage.

$k = 1/s_d$

ie = effective rainfall

S_d can be defined using the equation by Jones and Mitchell (1978):

$$S_d = aD^b \qquad (75)$$

where D = depth above the lowest point on the surface (inches) or m

a,b = constants to be determined.

TROPICS combines (D1) and (D2) and uses the final equation to calculate the depression storage. The new equation is:

$$Vd = a \cdot D^{b} \cdot \left(1 - e^{-1/a \cdot D^{-b} \cdot ie}\right)$$

Runoff starts when

$\Sigma\ Vdj \cdot \Delta tj = Sd$, i.e. when the sum of the depression incremental value vdj at time Δtj sums up to the maximum depression storage depth.

Estimation of D, a, b

1) D, value

Values of D were found for different soil types (Jones and Mitchell, 1978).

Table 3. Possible depression storage depths (Jones and Mitchell, 1978).

Soil Type	D (m)
Clay	0.24
Sand	0.18
Silt	0.24
Laterite	0.23
Loam	0.20

The above value can be used for D when data is not available for the site of study.

2) a,b values

For rough surface (case of tropical rain forest zones). The values of a,b found for rough surfaces (Jones and Mitchell, 1978) can be used. The average a and b values are:

$$\left.\begin{aligned} &a = 0.00491 \\ \text{and} \quad & \\ &b = 3.45 \end{aligned}\right\} \quad \text{unitless coefficients}$$

Evapotranspiration

The Et estimation in TROPICS model takes into account the diversity of Et sources discussed in Chapter 2. TROPICS handles five Et sources. The first Et value is Eto--the potential evapotranspiration value which is calculated by the Priestly-Taylor method. The second Et value is the evaporation value Ein obtained from water intercepted at the canopy surface. The third Et value is the evaporation Es from the water held at the soil surface in the forest. The two remaining Et terms are more of the transpiration type--the first of the kind, i.e. the fourth overall Et value is Etu. The plants transpiration for soil upper layer and Etl, the transpiration from plant root in the water table zone. The calculation of Et variables is described below.

1) The overall Et value: Eto

Eto in TROPICS is calculated by the Priestly-Taylor method referenced in Chapter 2. As discussed earlier, the equation is written as:

$$\text{Eto} = \text{alpha} * (\text{NRAD} - 6) * \frac{1}{\text{Lh}} * (\text{slopes}/(\text{slopes} + \text{psy}))$$

The key terms in the equation are discussed below.

The net radiation term: NRAD

NRAD = LWR + SWA + CSOLRA * 11.574 * (SPARAD/SPAS)

where: LWR = net language radiation

SWA = short wave absorbtivity of the plant canopy or soil surface (= 0.78).

CSOLRA = measures solar radiation (Mj m^{-2} d^{-1}) converted to weber by multiplication by 11.574.

SPARAD = Theoretical solar radiation above the atmosphere for a given time step in $W \cdot m^{-2}$.

SPAS = Theoretical solar radiation for a day ($W \cdot m^{-2}$)

NRAD = net radiation ($W \cdot m^{-2}$).

The net longwave radiation (LWR) is calculated assuming the soil or plant surface temperature is equal to the ambient air temperature.

LWR = (AE - SE) * ST * (ATempo + 273) **4 - 1 (76)

AE = atmospheric emissivity

SE = soil emissivity (= 0.97)

ST = Stephen-Boltzman Constant (=5.67 E - 08 W^{-2}K-4)

ATEMPE = Air temperature in °C but converted in k by the addition of the number 273.

The atmospheric emissivity (AE)

This term can be calculated according to Campbell (1985).

(4) AE = (1-0.84*clouds)*(0.32+0.005+Atemp)
+0.84*clouds (77)

clouds = fractional clouds cover with o ≤ clouds ≤ 1

Slope of the saturation of vapor density function (slopes)

Slopes is given by Luchs et al. (1978) by

Slopes = SVD*(((Lh*MW)/R)/(Atemp+273)-1)/(Atemp+273) (78)

MW = molecular weight (0.018 kg. $mole^{-1}$)

SVD = saturation vapor density (Gm^3).

SVD is given by Campbell.

SVD = (Exp(31.3716-6014.79)/(Atemp+273)
-0.00792495*(Atemp+273)))/(Atemp+273) (79)

Some parameters in the equations above need to be determined. These parameters are 1) SParad, 2) Atemp, and 3) Clouds.

The irradiance above the atmosphere is calculated according to Campbell (1977) as

SPARAD = SOLA * SOLARC (80)

where: Solar = solar constant (1360 Wm^{-2})

Sola = the sine of the solar elevation angle in degrees at a given time of the day. Sola is calculated according to Campbell (1977, 1985).

$$\mathrm{Sola} = \mathrm{SOLDA}*\sin(\mathrm{Lat}*0.01745) + \mathrm{Cos}(\mathrm{Lat}*0.01745) *\mathrm{Cos}(0.2618*(\mathrm{Time}-\mathrm{Tsn})/3600)*\mathrm{Csold}. \quad (81)$$

where: SOLDA = sine of the solar declination angle

Lat = latitude (degrees)

Tsn = time of solar noon

CSOLD = cosine of solar declination angle

SOLDA is calculated according to Swift (1976).

$$\mathrm{SOLDA} = 0.39785 \sin[4.869+0.0172\ \mathrm{JULDAY} + 0.03345* \sin(6.224 + 0.0172\ \mathrm{JULDAY}). \quad (82)$$

where JULDAY is the day of the year number

January 1 = 01; December 30 = 365.

The cloudiness is calculated according to Campbell (1985):

$$\mathrm{Clouds} = 2.33 - 3.3 * \mathrm{Tc} \quad (83)$$

where: Tc = transmission coefficient of the atmosphere.

$$\mathrm{Tc} = \mathrm{CSOLRA}/\mathrm{SOLRAD} \quad (84)$$

The potential evapotranspiration given by Priestly-Taylor's equation has the dimensions of $kg \cdot m^{-2} \cdot s^{-1}$. To convert ETO in units m/hr we have to divide ETO par $\rho_w = 1000\ kg/m^3$ and multiply it by 3600 sec.

$$\mathrm{ETo}' = \frac{\mathrm{ETO}}{\rho_w} \times 3600\ (m/hr)$$

if $\rho_w = 1000\ kg/m^3$

$$\mathrm{ETo}' = 3.6\ \mathrm{ETo}\ (m/hr). \quad (85)$$

Ets: total surface evaporation

Ets = Ein + Es where:

Ein = evaporation from canopy surface.

Es = forest floor evaporation.

1) Es: The value of surface evaporation was found to be very small in studies over tropical rain forest zones. Jordan (1977) in his study of Et in the ran forest of Venezuela reported a maximum Es value of 0.4 mm over three consecutive days. On the average he found Es to be very close to zero. The same result was reported by Leopoldo (1982a). In their Et study over in the Brazilian rain forest, the above authors found a zero Es value. They reported that most of the surface evaporation value was obtained from canopy interception. For the above reasons, TROPICS assumes that Es = 0 in its evapotranspiration calculations.

2) Ein: Since Es is assumed to be negligible in the tropical forest Ein (evaporation of intercepted water) is the most important factor in surface evaporation. In fact, Ets = Ein. Ein was found to be equal to 25% of the total Et value in the tropical Amazonian rain forest (Leopoldo 1982a). Sometimes Ein can even exceed the potential evapotranspiration rate ETo. Because of the fact that most of the intercepted water is evaporated Ein is assumed to be proportional to the intercepted water depth for a given time interval. Hence

$$Ein = k \cdot \Delta si \qquad (86)$$

and the k value isZ equal to 0·9 and Δsi is equal to the interception storage during a given time step Δti. In general, k can be chosen in the following range: $0.8 \leq k \leq 1.0$. K = 0.8 for slightly dense forest and k = 1.0 for very dense forest.

3) T: total transpiration

T is equal to Etl + Etu, where Etl is the plant transpiration from the lower soil profile and Etu is the transpiration from the upper soil layer.

a) Etu: Is the upper zone transpiration value. It is determined by the method proposed by Balek (1977).

$$Etu = \frac{\theta t - \theta wp}{\theta fc - \theta wp} \cdot ETo \qquad (87)$$

ETo: the potential Et computed using the modified Penman's equation.

θt: the soil water content at time t.

θwp: the soil water content at wilting point.

θfc: the soil water content at field capacity.

It was shown that most of the plants draw 90% of their water supply from the upper soil profile (Pruitt, 1977). This trend is very true in most tropical rain forest zones where trees do not have very deep root systems. For this reason, TROPICS assumes that proportionally to the water intake, the upper zone transpiration represents about 90% of the total transpiration process. That leaves about 10% of the total transpiration value to the lower zone transpiration term Etl.

b) The Etl value

The Etl value is about 10% of the total transpiration process. An equation has been developed to handle Etl in TROPICS.

$$Etl = ka \cdot \left(\frac{RMAXZD - dwT}{RMAXZD}\right) \cdot ETo \qquad (88)$$

Ka = constant coefficient.

RMAXZD = maximum root zone depth

dwt = water table depth.

a = 1

The RMAXZD varies from one rain forest zone to the other. RMAXZD is higher than the tropical rain forests of Africa and smaller in the Amazonian and Puerto Rican rain forests. RMAXZD is determined from soil studies.

c) How to determine the parameters of Etu and Etl expressions?

θwp and θfc are easy to obtain. A number of researchers have listed them for different soil categories (Eagleson, 1970), U.S.G.S., etc.

· RMAXZD varies with soil types and tree species. It can reach up to 8 meters (African rain forest) and 2 meters to a few inches in the Amazonian and Puerto Rican rain forests.

· dwt is variable and depends on the time of the year. dwt doesn't vary too much on the average in the tropical rain forest because of the abundant rainfall supply. Most of the rain forest zones average more than 3,000 mm of rainfall a year. Almost every month receives an appreciable amount of rainfall (Ewel and Whitmore, 1973).

$$\cdot\ Etl = \left(\frac{RMAXZD - \dot{d}wt}{RMAXZD}\right) Ka \cdot Eo$$

Obtain transpiration values (T) of the forest zone and corresponding dwt values. Take Etl = 0.1.T, then apply a logarithmic regression on the Etl equation

to

$$Ka = \frac{Etl}{Eo} \cdot \frac{RMAXZD}{RMAXZD - DWT} \tag{89}$$

When data are not available to calculate a, calculate T from

$$Etu = 0.9\ T \Rightarrow \left(T\ \frac{Etu}{0.9}\right)$$

and assume $Etl = 0.1\ T = \frac{Etu}{0.9} \times 0.1 = 0.11\ Etu.$

$$\underline{Etl = 0.11\ Etu} \tag{90}$$

3.3 Test and Model Verification

3.3.1 Application of the Model to a Puerto Rican Watershed in the Fajardo Region NE Puerto Rico

1) General description of the watershed

The Fajardo watershed was used to test the model. It is a basin of about 69 km^2 located in the Northeastern region of Puerto Rico, mostly in the rain forest regions Fig. 21). This zone is located between the latitudes 18° 14' 20"-18° 20' 00" and longitudes 65° 37' 30"-65° 4a7' 00" in the Northern Hemisphere. The Fajardo region is very humid. It receives more than 2300 mm of rainfall a year. The average temperature is about 25°C. The land elevation varies from 900.0 m.s.l. above mean sea level to 0.0 in the sea area. The existence of hourly rainfall data and daily flow records make it attractive for hydrologic simulation studies.

2) Precipitation Data

Table 5 shows the hourly precipitation data as reported by NOAA for the 3rd week of the month of May 1986.

3) Flow Records

The flow records for the period are also recorded in Table 5. The flow values are daily values for 1986.

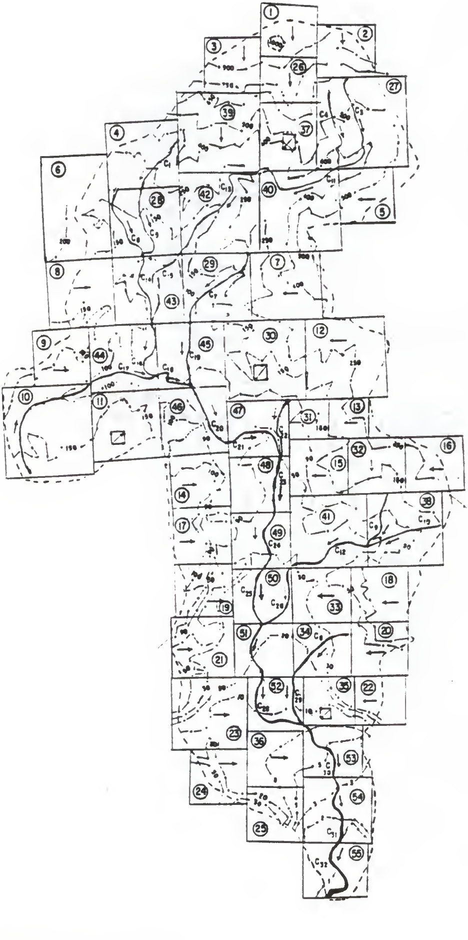
4) Vegetation and Soils

Most of the area is covered by the rain forest. The areas close to the sea are covered by "lighter" forest vegetation. The soil is dark and brown at the top and

Figure 21. Subdivision of the Fajardo Basin into elements, channels and flow directions.

LEGEND

—·—·–	Topo contours
━━━━	Channel representation
⟶	Flow direction in the element
▬ ▬ ▬	Basin divide
————	Element boundary
Ⓘ	Element number
C_n	Channel number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(55)

clayey, silty or lateric with loamy soil in the deeper soil layers. As reported by the Soil Conservation Service (1967), the lateric red clay is predominant in the area. The soil information and the vegetation data are reported in Table 5. Table 6 also shows the characteristics of the infiltration in the oxidized lateric soils of Puerto Rico according to Lugo-Lopez et al. (1968). In the present model five soil types were selected for simulation. The soil types are: 1) sand, 2) silt, 3) loam, 4) lateric, and 5) clay. Although the lateric is a type of clay (oxidized clay), it was chosen as a soil type because of its existence in different forms (artisoils, vertisoils, etc.) and its abundance in the area of study. All other soil and vegetation data used for the watershed are summarized in Table 5, in the files INFS.DAT, GRDWAT.DAT. Table 7 shows an example of field capacity water content and wilting point water content for the five types of soils which can be used in TROPICS.

5) The Channel System

The Fajardo region is a well-drained area with a lot of streams. In this study only the major streams were chosen for simulation. The rain stream is the Rio Fajardo which starts its course in the mountainous areas of the Pico del Este Mountain. The channels in the mountainous areas are steeper that those of the bay area near the city of Fajardo. For tropics only, 2-channel branches are allowed in

Table 5. Listing of a Sample of Input Files of TROPICS; Special Case of the Fajardo Basin.

---

1) File Old.dat: Original Weekly Discharges for Model Verification

```
                  Qob
                  M3/S

  9.7   3.71   2.38   0.91   0.54   1.36  13.82
```

---

2) File rain.dat: Hourly Precipitation Data for One Week

```
                  RR
                 M/HR

 0.00  0.00  0.00  0.00  0.00  0.25  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.76  0.25  0.51  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  1.02  2.03  0.76  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  1.27  0.00  0.00  0.25  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.51  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.25  0.00  0.00  0.00  0.25  2.03  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.25  0.00  0.25
 0.00  1.27  1.02  0.25  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.25  0.00  0.00  0.00  0.00  0.00  0.00
```

---

3) File Temp.dat: Temperature and ET Calculation Data

```
 Tmin   Tmax  Csolra
 O C     O C  MM/DAY

 20.0   30.0   5.24 134.0
 22.2   30.0   5.24 135.0
 22.2   29.4   5.24 136.0
 22.8   30.6   5.24 137.0
 22.2   31.1   5.24 138.0
 22.2   30.6   5.24 139.0
 19.4   30.6   5.24 140.0
```

Table 5 (continued)

4) Element Information Data. 1.

Element Label #	Element Level #	Class #	NUMB(I) Number of Adjacent Element	First Adjacent Element INC(I,1)	First Symbol SS(I,1)	2nd Adjacent Element INC(I,2)	2nd Symbol SS(I,2)	1st Adjacent Width WW(I,1)	2nd Adjacent Flow Width WW(I,2)
E_1	1	4	0						
E_2	1	4	0						
E_3	1	4	0						
E_4	1	3	0						
E_5	1	4	0						
E_6	1	4	0						
E_7	1	4	0						
E_8	1	4	0						
E_9	1	4	0						
E_{10}	1	3	0						
E_{11}	1	4	0						
E_{12}	1	4	0						
E_{13}	1	4	0						
E_{14}	1	4	0						
E_{15}	1	4	0						
E_{16}	1	4	0						
E_{17}	1	4	0						
E_{18}	1	4	0						
E_{19}	1	4	0						
E_{20}	1	4	0						
E_{21}	1	4	0						
E_{22}	1	4	0						
E_{23}	1	4	0						
E_{24}	1	4	0						
E_{25}	1	4	0						
E_{26}	2	4	1	E_1	V			1000.0	
E_{27}	2	3	1	E_2	V			1000.0	

Table 5 (continued)

4) Element Information Data. 1. (continued)

Element Label #	Element Level #	Class #	NUMB(I) Number of Adjacent Element	First Adjacent Element INC(I,1)	First Symbol SS(I,1)	2nd Adjacent Element INC(I,2)	2nd Symbol SS(I,2)	Adjacent Width WW(I,1)	2nd Adjacent Flow Width WW(I,2)
E_{28}	2	3	1	E_6	H			1000.0	
E_{29}	2	3	1	E_7	H			1200.0	
E_{30}	2	4	1	E_{12}	H			1400.0	
E_{31}	2	4	1	E_{13}	H			700.0	
E_{32}	2	4	1	E_{16}	H			1000.0	
E_{33}	2	3	1	E_{18}	H			1000.0	
E_{34}	2	3	1	E_{20}	H			1000.0	
E_{35}	2	4	1	E_{22}	H			900.0	
E_{36}	2	4	2	E_{23}	H	E_{24}	H	300.0	700.0
E_{37}	3	4	1	E_{26}	V			1000.0	
E_{38}	3	3	1	E_{32}	V			1000.0	
E_{39}	4	4	1	E_3	V			1000.0	
E_{40}	4	3	2	E_5	H	E_{37}	V	1000.0	1000.0
E_{41}	4	3	1	E_{32}	V			200.0	
E_{42}	5	3	1	E_{39}	V			1400.0	
E_{43}	6	3	1	E_8	H			1200.0	
E_{44}	7	3	2	E_9	H	E_{11}	V	1000.0	1200.0
E_{45}	8	3	1	E_{20}	H			1200.0	
E_{46}	9	3	2	E_{11}	H	E_{20}	H	1200.0	300.0
E_{47}	10	3	2	E_{30}	V	E_{31}	H	1000.0	700.0
E_{48}	11	3	2	E_{14}	H	E_{15}	H	900.0	700.0
E_{49}	12	3	1	E_{17}	H			900.0	
E_{50}	13	3	2	E_{19}	H	E_{33}	H	800.0	1000.0
E_{51}	14	3	1	E_{21}	H			1000.0	
E_{52}	15	3	2	E_{23}	H	E_{35}	H	1000.0	900.0
E_{53}	16	3	2	E_{35}	V	E_{36}	H	900.0	

Table 5 (continued)

4) Element Information Data. 1. (continued)

Element Label #	Element Level #	Class #	NUMB(I) Number of Adjacent Element	First Adjacent Element INC(I,1)	First Symbol SS(I,1)	2nd Adjacent Element INC(I,2)	2nd Symbol SS(I,2)	Adjacent Width WW(I,1)	2nd Adjacent Flow Width WW(I,2)
E_{54}	17	3	1	E^{25}	H		800.0		
E_{55}	18	3	0						

4) Element Information Data. 2.

Channel Label	Corresponding Channel Matrix	Element Containing Channel Number	Number of of Adjacent Channel Segment NADJAC(JJ(I))	First Adjacent Channel Segment NSC(JJ(I),1)	Second Adjacent Segment NSC(JJ(I),2)	Adjacent Channel # NCH(JJ(I))	IPREV(I)
C_1	JJ(4)	4	0				
C_2	JJ(10)	10	0				
C_3	$JJ_1(27)$	27	0				
C_4	$JJ_2(27)$	27	0				
C_5	$JJ_1(28)$	28	1			C_1	
C_6	$JJ_2(28)$	28	0				
C_7	JJ(29)	29	0				
C_8	JJ(34)	34	0				
C_9	$JJ_1(38)$	38	0				
C_{10}	$JJ_2(38)$	38	0				
C_{11}	JJ(40)	40	2	C_3	C_4		
C_{12}	JJ(41)	41	2				
C_{13}	JJ(42)	42	2	C_9	C_{10}		
C_{14}	$JJ_1(43)$	43	1			C_{11}	

Table 5 (continued)

4) Element Information Data. 2.

Channel Label	Corresponding Channel Matrix	Element Containing Channel Number	Number of of Adjacent Channel Segment NADJAC(JJ(I))	First Adjacent Channel Segment NSC(JJ(I),1)	Second Adjacent Segment NSC(JJ(I),2)	Adjacent Channel # NCH(JJ(I))	IPREV(I)
C_{15}	$JJ_2(43)$	43	2	C_5	C_6		
C_{16}	$JJ_1(44)$	44	2	C_{14}	C_{15}		
C_{17}	$JJ_2(44)$	44	1			C_2	
C_{18}	$JJ_1(45)$	45	2	C_{16}	C_{17}		
C_{19}	$JJ_2(45)$	45	1			C_7	
C_{20}	$JJ(46)$	46	2	C_{18}	C_{19}		
C_{21}	$JJ_1(47)$	47	1			C_{20}	
C_{22}	$JJ_2(47)$	47	1				
C_{23}	$JJ(48)$	48	2				
C_{24}	$JJ(49)$	49	1	C_{21}	C_{22}		
C_{25}	$JJ_1(50)$	50	1			C_{23}	
C_{26}	$JJ_2(50)$	50	1			C_{24}	
C_{27}	$JJ(51)$	51	2	C_{25}	C_{26}		
C_{28}	$JJ_1(52)$	52	1			C_{27}	
C_{29}	$JJ_2(52)$	52	1			C_8	
C_{30}	$JJ(53)$	53	2	C_{28}	C_{29}		
C_{31}	$JJ(54)$	54	1			C_{30}	
C_{32}	$JJ(55)$	55	1			C_{31}	

Table 5 (continued)

5) File Ovl.dat : Overland Flow Input Data

Why0 M	AA M	Slpe	Alpha3 Degrees
0.00	1000.0	0.100	270.0
0.00	1000.0	0.250	270.0
0.00	1000.0	0.150	270.0
0.00	1200.0	0.110	0.0
0.00	1000.0	0.100	180.0
0.00	1000.0	0.050	0.0
0.00	1200.0	0.125	180.0
0.00	1200.0	0.042	0.0
0.00	1000.0	0.050	0.0
0.00	1600.0	0.023	0.0
0.00	1200.0	0.036	45.0
0.00	1400.0	0.176	180.0
0.00	700.0	0.143	180.0
0.00	1000.0	0.050	0.0
0.00	1000.0	0.100	180.0
0.00	1000.0	0.083	180.0
0.00	1000.0	0.050	0.0
0.00	1000.0	0.133	180.0
0.00	1000.0	0.070	0.0
0.00	1000.0	0.250	180.0
0.00	1100.0	0.064	0.0
0.00	900.0	0.050	180.0
0.00	1320.0	0.030	0.0
0.00	1000.0	0.041	0.0
0.00	1000.0	0.045	0.0
0.00	1000.0	0.250	270.0
0.00	1600.0	0.156	0.0
0.00	1200.0	0.125	0.0
0.00	1200.0	0.035	0.0
0.00	1400.0	0.080	240.0
0.00	700.0	0.086	180.0
0.00	1000.0	0.050	270.0
0.00	1000.0	0.020	180.0
0.00	1000.0	0.014	0.0
0.00	900.0	0.017	225.0
0.00	1000.0	0.005	0.0
0.00	1000.0	0.286	225.0
0.00	1300.0	0.070	0.0
0.00	1400.0	0.286	270.0
0.00	1400.0	0.107	0.0
0.00	1300.0	0.033	0.0
0.00	1400.0	0.050	0.0
0.00	1200.0	0.042	0.0
0.00	1200.0	0.031	0.0

Table 5 (continued)

5) File Ovl.dat : Overland Flow Input Data

WhyO M	AA M	Slpe	Alpha3 Degrees
0.00	1200.0	0.020	0.0
0.00	1200.0	0.020	0.0
0.00	1000.0	0.010	0.0
0.00	1000.0	0.020	0.0
0.00	1000.0	0.020	0.0
0.00	1000.0	0.010	0.0
0.00	1000.0	0.010	0.0
0.00	1000.0	0.010	0.0
0.00	1000.0	0.005	0.0
0.00	1200.0	0.002	0.0
0.00	1000.0	0.001	0.0

---

6) File Interl.dat: First Interception Input Data File

Km2
1.00
1.00
1.00
1.44
1.00
1.00
1.44
1.44
1.00
2.56
1.44
1.96
0.50
1.00
1.00
1.00
1.00
1.00
1.00
1.00
1.21
0.81
1.74
1.00
1.00
1.00
2.56

Table 5 (continued)

6) File Inter1.dat: First Interception Input Data File

Km2
1.44
1.44
1.96
0.50
1.00
1.00
1.00
0.81
1.00
1.00
1.69
1.96
1.96
1.69
1.96
1.44
1.44
1.44
1.44
1.00
1.00
1.00
1.00
1.00
1.00
1.00
1.44
1.00

7) File Inter2.dat: Second Interception Input Data File

DS CM	M # Trees/HA
10.0	6000
20.0	1700
30.0	700
40.0	400
50.0	250
60.0	180
70.0	160
80.0	100
90.0	70
100.0	30

Table 5 (continued)

8) File Infdsp.dat: Infiltration Data

Rate %/HR	Wacs	SAV M	DE M	WIC	HKS CM/HR	DEL M
0.083	0.43	0.0534	0.12	0.10	0.1178	0.1750
0.083	0.43	0.0534	0.12	0.10	0.1178	0.1750
0.083	0.43	0.0534	0.12	0.10	0.1178	0.1750
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.0002	0.41	0.2772	0.60	0.27	0.0003	0.2360
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.0002	0.41	0.2772	0.60	0.27	0.0003	0.2360
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.0002	0.41	0.2772	0.60	0.27	0.0003	0.2360
0.0002	0.41	0.2772	0.60	0.27	0.0003	0.2360
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.0002	0.41	0.2772	0.60	0.27	0.0003	0.2360
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.001	0.45	0.2800	0.50	0.28	0.0004	0.2300
0.0002	0.41	0.2772	0.60	0.27	0.0003	0.2360
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0046	0.49	0.1700	0.30	0.20	0.0065	0.2400

Table 5 (continued)

8) File Infdsp.dat: Infiltration Data

Rate %/HR	Wacs	SAV M	DE M	WIC	HKS CM/HR	DEL M
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.25	0.0034	0.2030
0.0024	0.44	0.0900	0.19	0.29	0.0034	0.2030

9) File Chanl.dat: First Channel Input Data File

RLEN M	HTOTC M	XX	Slop
1200.00	250.00	0.25	0.150
2400.00	90.00	0.25	0.025
1800.00	300.00	0.25	0.150
1400.00	300.00	0.25	0.180
1500.00	100.00	0.25	0.067
1300.00	100.00	0.25	0.077
1600.00	90.00	0.25	0.069
1260.00	15.00	0.25	0.024
1000.00	40.00	0.25	0.050
1400.00	40.00	0.25	0.036
1600.00	250.00	0.25	0.031
1500.00	30.00	0.25	0.007
2400.00	100.00	0.25	0.063
1300.00	100.00	0.25	0.008
1500.00	100.00	0.25	0.007
1200.00	85.00	0.25	0.008
1200.00	85.00	0.25	0.008
1000.00	80.00	0.25	0.010
1200.00	80.00	0.25	0.008
1200.00	70.00	0.25	0.017
1200.00	50.00	0.25	0.008
1000.00	50.00	0.25	0.040
1000.00	40.00	0.25	0.010
1200.00	25.00	0.25	0.013
1000.00	22.00	0.25	0.003
1100.00	22.00	0.25	0.009
1200.00	15.00	0.25	0.004
1600.00	9.00	0.25	0.004

Table 5--continued

9) File Chanl.dat: First Channel Input Data File

RLEN M	HTOTC M	XX	Slop
1000.00	9.00	0.25	0.006
1200.00	4.00	0.25	0.004
1200.00	1.00	0.25	0.003
1400.00	0.50	0.25	0.001

---

10) File Reg.dat: Regression Input Data File

SURF Km2	QQR M3/S
3.5400	42.50
0.2268	2.62
0.0047	0.17
0.6300	22.33
1.0938	38.60
14.7267	520.00
4.0498	143.00
15.2648	539.00
8.8077	311.00
2.6706	94.30
4.7295	47.70
10.5069	149.52
4.5313	142.00
0.5466	8.42
0.5126	9.69
0.5353	26.40
1.3537	20.44
16.0011	233.00
2.0100	71.20
4.4463	39.00

---

11) File Chan3.dat:

CONCEN Mg/L	AREA1 Km2
14.57	1.44
14.57	2.56
14.57	2.56
14.57	1.00
14.57	1.68
14.57	2.20
6.51	2.48

Table 5--continued

11) File Chan3.dat:

14.57	2.00
14.57	2.29
14.57	1.10
14.57	7.02
14.57	5.38
14.57	24.44
14.57	4.63
14.57	25.13
25.23	30.36
14.57	5.12
6.51	30.07
6.51	4.85
25.23	36.58
25.23	37.08
25.23	4.15
25.23	44.23
25.23	46.23
25.23	48.28
25.23	7.33
25.23	57.82
25.23	58.77
25.23	3.79
25.23	65.56
25.23	68.00
25.23	69.00

12) File Grdwat.dat: Groundwater Flow Input Data File

PCO	HCO	WP	FC	COEFF M3/S	RMAXRZD M	DMAX M
2.0	8.0	0.0333	0.1115	0.00078	1.75	3.00
2.0	8.0	0.0333	0.1115	0.00078	1.75	3.00
2.0	8.0	0.0333	0.1115	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
40.0	24.0	0.0370	0.1233	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00

Table 5--continued

12) File Grdwat.dat: Groundwater Flow Input Data File

PCO	HCO	WP	FC	COEFF M3/S	RMAXRZD M	DMAX M
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
40.0	24.0	0.0370	0.1233	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
40.0	24.0	0.0617	0.1233	0.00078	1.75	3.00
40.0	24.0	0.0370	0.1233	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
40.0	24.0	0.0370	0.1233	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
47.0	20.0	0.0617	0.1116	0.00078	1.75	3.00
40.0	24.0	0.0370	0.1233	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
20.0	19.0	0.0344	0.1149	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00
30.0	9.0	0.0349	0.1166	0.00078	1.75	3.00

Table 5--continued

13) File Lake.Dat: Lake Input Data File

APL M	AL Km2	SLAKE	NR
0.00	0.00	0.00	0.00

Table 6. Eight hour infiltration rate of different lateric soils in Puerto Rico after Lugo-Lopez et al., 1968.

Soil Group	Minimum Infiltration Rate (cm/hr)	Maximum Infiltration Rate (cm/hr)
Vertisoils	0.18	9.58
Entisoils	2.32	27.55
Inceptisoils	2.75	13.25
Alfisoils	2.78	11.58
Mollisoils	8.22	19.55
Oxisoils	8.45	15.40
Ultisoils	7.40	23.68

each element. For the Fajardo basin, a total of 32-channel segments were assigned numbers for the simulation. The characteristics of different channels are reported in Table 5 under the file names, CHAN1.DAT, CHAN3.DAT and GRDWAT.DAT.

6) The Depression Storage Depths

They are the same as mentioned in Chapter 3.2 process modeling. The depression storage values for various soil types is also summarized in Table 7 under File INFDSP.DAT.

7) Lake and Reservoirs

The basin doesn't contain any major lake or reservoir to be considered in the model.

8) Groundwater

The groundwater in formation is regrouped under the file GRDWAT,DATA in Table 5. The different variables used are described in Table 4.

9) The overland flow data or basin data. To obtain the overland flow for simulation, the watershed of the Fajardo basin was divided into square elements. The size of square elements with channel segments was larger or equal to 1 km. Such restriction doesn't exist for non channel elements. The number of squares for the watershed NEL is equal to 55. Flow direction angles and the classification of element were performed as described in Chapter 3. The data generated are summarized in Table 7 under the file names OVL.DAT, INTER1.DAT, and the element DATA description.

Table 7. Wilting point and field capacity of different types of soils.

Soil Types	Wilting Point Water Content	Field Capacity Water Content
Sand	0.03	0.08
Silt	0.17	0.28
Loam	0.14	0.26
Lateric	0.225	0.32*
Clay	0.26	0.36

*not in original table.

10) Discussion on the Output of TROPICS (Case of the Fajardo Watershed)

The output from TROPICS is the same as described in Chapter 3. The Input Data can be printed with the output data as desired by the user. The first non optional output is the data ordered according to the minimum interevent time which is 2 hours for the area. The number of events here is 12 (NEWC = 12). The time values of the 12 events are listed under the parameter time (hr) in the heading. The model reproduces very well the different events when compared to the original data. The next output values are the hourly temperature values given in °C. TROPICS converts the daily minimum and maximum temperatures into hourly data according to a sine function. The hourly daily values compared to the daily data seems reasonable. The ET values predicted seem acceptable. After the ET values comes the computation of variables such as canopy density, throughfall (i.e. rainfall minus interception), rainfall excess (runoff) and infiltration for each of the 55 square elements of the basin. The output data for the variables are given in Appendix B. The maximum canopy density is 100% (canopy density of element #10) and the minimum canopy density is 24% (element #13).

After the output from each element TROPICS gives the regression data values of the regression analysis after printing the data used for the regression. In the option when there is no initial velocity or discharge and channel data, the values of those variables are calculated using the formulas of Stevens and Nordin (1990). The next series in the output is the report of discharge values. These values are given by events. The program then plots the discharge values for each event. The results obtained here by prediction have a 93% correlation with the recorded values. The predicted values seems acceptable.

3.4 Limitations and Strengths of the Model

TROPICS, like other computer models, has its weaknesses and strengths.

3.4.1 Limitations of TROPICS

a) The distributed modeling concept requires a lot of input data. TROPICS is no exception. However, as time goes on, some improvements may occur and lead to a reduction of the amount of data needed to run TROPICS.

b) The model is built for tropical zones and may not give good results for temperate zone basins. But the guess here is that with a careful choice of parameter TROPICS will be used to simulate hydrological variables in temperate zones.

c) Erosion and transport of sediment are factors which really affect the hydrologic cycle of tropical zones. The two processes, however, could not be modeled in TROPICS because of the lack of certain information for an adequate study. Water quality and non point source pollution is also not handled in the model. The study of these parameters will be done for future releases of TROPICS assuming that the information is made available.

d) TROPICS cannot be used to model hydrologic variables in basins less than 1 km^2 which have channel segments crossing them.

3.4.2 Strengths of TROPICS

a) TROPICS handles more than 1 channel segment in a given square element which is an advantage over other distributed models like ANSWERS which can route the flow through only 1 channel segment in a square.

b) TROPICS accounts for canopy variability and the resistance of trees to flow. These two factors are necessary to be considered in rain forest zones because of the presence of a multitude of trees. The canopy density in itself can help have an idea on how deforestation affects runoff.

c) Being a distributed and a physically based model, the variation of flow parameters can be known for a given location.

d) The Priestly-Taylor method used to predict evaporation doesn't involve the determination of the aerodynamic resistance to vapor transfer (R_2) for a soil surface and the knowledge of the wind speed which are necessary data to calculate ET in the Penman Equation. In addition, the equation is given to calculate ET in vegetative areas.

e) Most of the equations are chosen because of their ability to model hydrological variables in tropical zones.

3.5 Guidelines for TROPICS Users

This chapter will help a user to set the input data files in order to run TROPICS. TROPICS is written in Fortran 77. This first release has been tested on the vax computer system at the University of Florida. A PC version has not yet been developed. Prior to loading the data, care should be taken to have all the Input files correctly organized. This will save time and decrease input errors and program interruptions.

The ordering of elements into different levels, into channel and non channel elements, the specification of adjacent and non adjacent elements, and the determination of each channel adjacent channel segment, should be carefully done before building the input files. Once the data files are built and the program loaded into the vax computer memory, TROPICS is run after it is compiled and linked. The errors message are those of the Fortran 77 computer language errors. To make the running of TROPICS easier, an effort is made here to give as much information as possible about the setting of data files.

Table 4 has been made for that purpose. It gives the format field of the data variable, the name of the variable and its description. In the format field No. give the rank of the variable in the input file heading (see Table 4); size gives the format size specification Fd·n for reals and I_n for integers.

All integers must be right justified and all floating point decimals must use a decimal point to assure the proper value is used. During run time, care should be taken to input the proper parameter at each computer prompt. Otherwise one might get unreasonable results on output. When an error occurs in running the program, the user should refer to the chapter dealing with that error (i.e. if it is suspected that a subroutine is not adequately returning a value, check Chapter 3.2 to find the description of the appropriate subroutine and make the correction).

Description of Input Files

The different input files and their descriptions are given in the following table.

Table 4. Format field and description of input files and variables of TROPICS.

---

1) File OLD.DAT: Initial weekly discharges in m^3/s

Format Field No. 1	Size	Variable	Description of Variables
1	7(1X,F6·2)	QoB	Daily discharges over a week period

2) File RAIN.DAT: Hourly precipitation data in (M/hr): 168 data points

Format Field No. 1	Size	Variable	Description of Variables
1	12(1X,F5·3)	RR	Hourly rainfall data

3) File TEMP.DAT: Temp and specifications data

Format Field No. 1	Size	Variable	Description of Variables
1	F6·2	Tmin	Minimum daily temperature in (°C)
2	F6·2	Tmax	Maximum daily temperature in (°C)
3	F6·2	CsolRA	Measured daily solar radiation in (MM/day)
4	F6·2	RJLDAY	Day's number in Julian day classification (01 January = 01; Dec. 31 = 365)

4) Element Information DATA (or BASIN DATA)

Format Field No. 1	Size	Variable	Description of Variables
1	In	Integer	Element #
2	In	Integer	Element level #
3	In	Class	Element classification according to the criteria of the element having channel or not, or draining to a lake or not (not to be input but handy to know)
4	In	NUMB(I)	Number of elements adjacent to a given element I (The adjacent element has a certain percentage of its flow directed to its neighboring element).
5	In	INC(I,K_J)	Integer variable indicating the adjacent element # in the overall classification of elements form 1 to NEL (NEL = Total # of elements in the Basin). INC is the K_Jth element adjacent to element I. KJmax = 6 in TROPICS.
6	A_1	SS(I,K_J)	Character variable taking the value of "H" or "V" indicating the flow direction from element INC(I,K_J) to element I. "V" = vertical flow; "H" = Horizontal Flow.
7	Fd·n	WW(I,K_J)	Flow width of adjacent element INC(I,K_J) to element I.
8	In	Integer	Channel #.

9	In	JJ(I), $JJ_1(I)$ $JJ_2(I)$	Matrix of channel # JJ(I); channel # JJ(I) is within element I $JJ_1(I)$: First channel segment of Element I when the element has 2 channel segments crossing it. $JJ_2(I)$ is the second channel segment # in case of two channel segments crossing the element.
10	In	Integer	Element # containing a given channel #.
11	In	NADJAC (JJ(I))	Number of channel segments adjacent to channel segment JJ(I) lying within element I. NADJAC(JJ(I)) = 1 or 2.
12	In	NCH(JJ(I))	Number of channel segments adjacent to channel segment JJ(I). (This # varies from 1 to NTOFC (total # of channel segments in the Basin).
13	In	NSC(JJ(I),1) NSC(JJ(I),2)	First and second channel number adjacent to a given channel segment JJ(I) when JJ(I) has 2 channel segments adjacent to it.
14	In	IPREV(I)	Element # when a 2 channel element drains to a given element.

- -

5) File OVL.DAT: Overland Flow Calculation Data

Format Field No. 1	Format Field Size	Variable	Description of Variables
1	F7·4	WHYO	The initial flow depth in the element (M)

2	F8·2	AA	Element side length in (M)
3	F8·6	SLPE	Overland flow slope
4	F6·1	ALPHA3	Angle of flow in degrees

- -

6) File Inter1.DAT: First Interception Data File

Format Field No. 1	Size	Variable	Description of Variables
1	F6·2	A11	Element area (km^2)

- -

7) File Inter2.DAT

Format Field No. 1	Size	Variable	Description of Variables
1	F6·1	DS	Diameter of tree species in the Basin (cm)
2	I_8	M	Number of trees/the diameter DS in the Basin

- -

8) File INFDSP: Data for Infiltration and Depression Storage Calculation

Format Field No. 1	Size	Variable	Description of Variables
1	F7·4	RATE	Rate of change of soil moisture in soil (%/hr)
2	F4·2	WACS	Saturation water content
3	F6·4	SAV	Wetting front tension (m)
4	F4·2	DL	Depth of Humectation (cm)

5	F4·2	WIC	Initial water content
6	F4·2	HKS	Hydraulic conductivity (M/hr)
7	F7·4	DE	Depression depth (M)

- -

9) File Chani.DAT: First Channel Information File (optional)[2]

Format Field		Variable	Description of Variables
No. 1	Size		
1	F7·2	RLEN	Channel length in (M)
2	F7·2	HTOTC	Soil surface elevation in (M)
3	F4·2	XX	Muskingum X
4	F8·6	Slop	Channel slope
5	F4·2	WIC	Initial water content

- -

10) File Chan2.DAT: Second Channel Data (optional)[2]

Format Field		Variable	Description of Variables
No. 1	Size		
1	F4·2	VM	Channel initial velocity (M)
2	F8·4	HC	Channel bottom elevation (M)
3	F6·3	QQo	Channel discharge $(M^3/5)$
4	F8·4	YYO	Initial water depth in Channel (m)
5	F8·4	HWC	Initial water level in channel

- -

11) File REG.DAT: Regression Data File for $Q = \alpha A\beta$ (optional)^2

Format Field		Variable	Description of Variables
No. 1	Size		
1	F8·4	QQR	Discharges of the river (M^2/S)
2	3X, F7·2	SURF	Area of Basin (km^2)

- -

12) File Chan3.DAT: Data for Channel Characteristic Determination

Format Field		Variable	Description of Variables
No. 1	Size		
1	F7·3	CONCEN	Sediment concentration in channels (mg/2)
2	2X, F7·2	Arel	Area in (km^2)

- -

13) File GRDWAT.DAT: Data for groundwater flow computations

Format Field		Variable	Description of Variables
No. 1	Size		
1	F7·4	PC_O	Constant in groundwater Calculation
2	F7·4	HC_O	Constant in groundwater Calculation
3	F6·4	WP	Wilting point water content
4	F6·4	FC	Field capacity water Content
5	F7·3	COEFF	Potential groundwater release (m^3/S)

6	F5·2	RmaxD	Maximum unsaturated zone Depth (m)
7	F5·2	Dmax	Depth of water table fluctuation

---

14) File INLAKE.DAT: Data for lake routine calculation

Format Field No. 1	Size	Variable	Description of Variables
1	F8·2	ApL	Lake entrance structure width (m)
2	F6·2	AL	Lake area (Bm^2)
3	F8·6	Slake	Lake slope content
4	F7·3	NR	Manning roughness

Footnotes:

1) All the elements in the format except specified (ex.: 3X, F7·2) are separated by a blank, i.e. 1X.

2) Optional means that the user has an option in choosing that input File or another.

Other Input Data:

Most of these data types are interactively input. They are:

NEL: Total # of elements in the Basin NEL_{max} = 55.

T_L: Minimum interevent time in Hrs.

IF_1, IF_2, IF_3...If_n: are flag to indicate if the input should be printed with the output.

Ntote: Total # of channel segments in the watershed.

N_3: Number of elements without channel segment.

N_4: Number of elements with channel.

ANS: Flag indicating whether 2 channel segments drain to a lake (Format A_3).

ANS_1: Flag indicating whether the elements drain to a lake or not (A_3).

ANS_2: Flag indicating whether the element has a channel segment or not (A_3).

Nume: Number of elements in the channel.

ANS_3: Flag indicating whether a given channel segment is an outlet element of a lake (character field A_3).

ANS_4: Flag indicating if the second channel segment is a lake outlet element (character Field A_3)

Flag: Flag taking a value of 1 or 0 indicating whether the basin has a lake or not.

NL: Number of tree species of diameter DS in the basin.

NREG: Number of regression points in the relation

$$Q = \alpha A^{\beta}.$$

Complete with EKay, AB, BA, Alpha2, Beta, S_{max}, BNAME, BSAREA, Lat C_D (see attached sheet).

CHAPTER 4
CONCLUSION

4.0 Discussion

The objectives assigned for this research were to develop a computer model to generate a weekly hydrograph at the outlet of a tropical basin, by accessing the characteristics of tropical rain forest, to establish equations to model the processes and linking them together and to apply the model to a chosen tropical rain forest watershed.

Since the model was developed and the final results were obtained the objectives have been achieved. But the most important thing now is to know if the results are acceptable. From the test on the Fajardo Basin the results seem satisfactory. However, more watersheds from other tropical regions (Africa, India, Australia) should be used to run the model. This may result in the regionalization of certain parameters within the tropical areas of the world. This is to say that there is room for improvement for TROPICS. Furthermore, changes can be made to include the estimation of erosion, sediment transport, and water quality studies. The concept introduced in the model which is to use the drag force on trees and account for resistance to flow is a major satisfaction because of the overall results obtained. The ability to obtain the discharge associated to the change of canopy density seems very important for the hydrological studies of the tropical rainforest. Our guess is that this is just the first release of TROPICS and improvements will be made soon. These improvements and the obtention of good calibration data will help refine the model. They will lead to a better match of measured and predicted discharge values and correct the discrepencies observed at a few data point on the plot of the hydrographs obtained by simulating TROPICS on the Fajardo basin of Puerto rico.

APPENDIX A
LIST OF VARIABLES AND SYMBOLS

List of Program Variables and Symbols

NEL: Total number of elements in the basin.

NTOTC: Total number of channel segments in the watershed.

N_3: Number of elements without channel segments.

N_4: Number of elements with channel.

ANS: Flag indicating whether 2 channel segments drain to a lake.

ANS_1: Flag indicating whether the element drains to a lake or not.

ANS_2: Flag indicating whether the element has a channel segment or not.

ANS_3: Flag indicating whether a given channel segment is an outlet element of a lake.

ANS_4: Flag indicating a second channel segment is a lake outlet element.

Flag: Flag variable taking a value of r when the basin contains a lake and o when the basin doesn't contain a lake.

NL: Number of tree species of different diameters (DS) in the basin.

NRED: Number of regression points in the equation

$$Q = \alpha A^{\beta}.$$

I: Element index.

J: Time index.

NFirst(J): First time value in an event in (hr).

NLast(J): Last time value in an event in (hr).

RFirst(J): First rainfall value in an event in (mhr^{-1}).

RLast(J): Last rainfall value in an event in (m/hr).

RATE(I): Depletion rate of soil moisture (%hr^{-1}).

WACS(I): Saturation water content in element I (cm^3/cm^3).

SAV(I): Wetting front suction (m).

DL(I): Depth of Humectation (m).

WIC(I): Initial soil water content in element I(cm^3/cm^3).

HKS(I): Hydraulic conductivity (mhr^{-1}).

POR(I): Porosity of the soil in element I.

RMAX2D(I): Maximum roof zone depth (m).

WP(I): Wilting point water content.

FC(I): Field capacity water content.

Dmax(I): Depth of water table fluctuation (m).

COEFF: Potential groundwater release (m^3/s).

Tmin: Minimum daily temperature value in degrees centigrade (°C).

Tmax: Maximum daily temperature value (°C).

CSOLRA(J): Measure daily solar radiation (mmday^{-1}).

RJLDAY: Day's number in Julian day classification (January 1 = 01, Dec. 31 = 365).

DT: Computation time increment.

Ktime(J): Time values (hr).

R(J): Raw rainfall data (mhr^{-1}).

NF_3(J): Starting time value for event J (hr).

NL_3(J): End time value for event J (hr).

$RL_3(J)$: Last rainfall value for event J (mhr^{-1}).

ATEMP(ℓ,J): Hourly temperature value °C in day ℓ at time J of the day.

Concen(K): Sediment concentration in (mg/ℓ) in channel number K.

QQR(n): Discharge values for regression analysis (m^3s^{-1}).

SURF(n): Area values for regression analysis (km^2).

$ARE_1(n)$: Area values for QQR calculations (km^2).

QH(J,I): Horizontal component of the water discharge QOVA (m_3s^{-1}).

QHH(J,I): Horizontal flow from adjacent element (m^3s^{-1}).

QV(J,I): Vertical component of the water discharge QOVA (M^3/S).

QVV(J,I): Vertical flow from adjacent element (M^3/S).

INC(I,K_J): Integer variable number of the K_Jth element adjacent to element I.

NSC(JJ(I),K): Label number of Kth channel segment adjacent to channel segment JJ(I) which crosses element I.

SS(I,K_J): Character variable taking the value of H or V indicating the flow direction from one element to the other (H = horizontal direction, V = vertical direction).

NUMB(I): Number of elements adjacent to a given element I.

JJ(I): Label number of channel segments lying within element I when the element has one channel segment.

$JJ_1(I)$: Label number of the first channel segments lying within element I for a two channel segment element.

$JJ_2(I)$: Label number of second channel segments for a two channel segment element.

NCH(JJ(I)): Label number of channel segments adjacent to a channel segment JJ(I).

NADJAC(JJ(I)): Number of channel segments adjacent to channel segment JJ(I).

NUME(I): Number of channel segments in a given element I.

NTIME(J), ITIMEX(J): Time parameters (hr).

Level(I): Element level number in the element classification scheme.

$T_B(J)$,$T_BNEW(J)$: Times between event J and event JH (hr).

Class(I): Class of the element.

NCount: Total number of non-zero rainfall values among the 168 hourly rainfall data.

IPREV(I): Label of element of two channel segments draining into a given element I.

M(n): Number of trees/ha for the tree class n.

ALPHA3(I): Angle of flow in degrees in element I.

AA(I): Element side length (m).

QI(J,I): Inflow to overland flow element I at time J.

IFlag1(JJ(I)): Flag indicating whether the channel segment JJ(I) is a lake outlet element.

Slop(JJ(I)): Slope of channel JJ(I).

PCo(I): Constant in groundwater flow calculation.

QBAR(J,I): Average flow from overland flow routine (m^3s^{-1}).

PRUNOF(J,I): Runoff from element I at time J.

RAINF2(J): Rainfall value at time J (hr) in flow ordering routine.

GWR(J,I): Groundwater release from an element I at time J.

THETA(J,I): Water content value at time J from element I.

H(J,JJ(I)): Water elevation in channel segment JJ(I) at time J.

QOVA(J,I): Overland flow from element I at time J.

RR(J): Raw rainfall data value at time J (mhr^{-1}).

Qouto(J): Outflow discharge (m^3s^{-1}) value in one dimensional array form for the last element of the watershed.

Qoutot(J,I): Outflow from element I at time J in (m^3s^{-1}).

Eo(J): Evaporation at time J ($mmhr^{-1}$).

C_0(JJ(I)): First Muskingum coefficient for flow routing.

C_1(JJ(I)): Second Muskingum coefficient for flow routing.

C_2(JJ(I)): Third Muskingum coefficient for flow routing in channel segment JJ(I).

RK(JJ(I)): Muskingum K value for channel JJ(I) (Hr).

QCI(J,JJ(I)): Inflow into channel JJ(I) at time J (m^3s^{-1}).

QCO(J,JJ(I)): Pure channel outflow at times from channel JJ(I).

Qout(J,JJ(I)): Qout(J,I): overall outflow from a channel segment JJ(I) or total flow from a channel element (m^3s^{-1}).

XX(JJ(I)): Muskingum X value.

QOL(J): Outflow from lake at time J (m^{3}s^{-1}).

VM(JJ(I)): Average water velocity from channel JJ(I) (m^{3}s^{-1}).

QOB(J): Daily discharge over the week of study (m^{3}s^{-1}).

ERR$_1$(J): First error term in correlation coefficient calculation.

ERR$_2$(J): Second error term in correlation coefficient calculation.

QREAD(J,JJ(I)): Hourly discharge values obtained from daily values over the week period (m^{3}s^{-1}).

HC(JJ(I)): Bottom elevation of channel JJ(I) (m).

HWC(JJ(I)): Water level elevation in channel JJ(I) (m).

YYO(JJ(I)): Initial channel depth (m).

HTOTC(JJ(I)): Land surface elevation of element I, containing the channel segment JJ(I).

QQO(JJ(I)): Initial discharge from channel segment JJ(I).

WHYO(I): Initial overland flow depth (m).

NR: Manning roughness.

FIL(J,I): Infiltration from element I at time J (mhr^{-1}).

PARAM(I): Overland flow calculation parameter.

DDC(I): Canopy density.

THRG(I,J): Throughfall from element I at time J (mhr^{-1}).

Sinter(I,J): Interception storage from element I at time J (m).

DSIN(I,J): Incremental interception storage at time J from element I (m).

EXCESS(I,J): Rainfall excess at time J from element I.

DE(I): Depression storage depth of element (m).

ALL(I): Element side length (m).

RLen(JJ,(I)): Channel length (m).

SLPE(I): Overland flow slop for element I.

HC_0(I): Constant in groundwater flow calculation.

Y(J,I): Overland flow depth of element I at time J.

ALPHA2: Coefficient for canopy density calculation.

BETA: Coefficient for canopy density calculation.

SMax: Maximum interception depth (m).

DS(n): Diameter of tree specie n.

REYNOL: Reynold number.

Nu: Kinematic viscosity.

SPARAD(K,J): Space radiation at time J or day K $W \cdot m^{-2}$.

LWR(K,J): Net long-wave radiation (LWR) $W \cdot m^{-2}$.

G(K,J): Soil heat flux at time J of day K ($W\ m^{-2}$).

SOLA(K,J): Sine of polar elevation angle.

SOLARC: Solar constant = 1360 $W \cdot m^{-2}$.

Lh: Latent heat of vaporization of water ($j \cdot g^{-1}$).

Mw: Molecular weight.

SVD: Saturation vapor density (g/m^3).

SPAS(k): Theoritized solar radiation for a day ($W \cdot m^{-2}$).

Lat: Latitude in degrees of the area.

PSYCON: Psychrometric constant = 0.49 $g \cdot m^{-3} \cdot K^{-1}$.

Clouds: Fractional cloud cover.

AE: Atmospheric emissivity.

R: Gas constant = 8.3143 $J \cdot mole^{-1} \cdot k^{-1}$.

TSN: Time of solar noon (hr).

APL: Lake entrance structure width (m).

AL: Lake area (km^2).

Slake: Lake slope.

$WW(I,K_J)$: Flow width of adjacent element $INC(K,K_j)$ to element I.

BSAREA: Basin area in km^2

BNAME: Twenty character long variable indicating the name of the basin of study.

APPENDIX B
LISTING OF COMPUTER CODE

```
C***************************************************************
C*            T R O P I C S   V E R S I O N   1                *
C***************************************************************
C*THIS IS TROPICS ; A COMPUTER MODEL BUILT TO DETERMINE THE    *
C*FLOW OF WATER AT THE OUTLET OF A TROPICAL BASIN. OBSTRUC-    *
C*TION TO FLOW BY TREES IS TAKEN INTO CONSIDERATION IN THE     *
C*MODEL. THE FIRST RELEASE OF TROPICS PREDICTS AND PLOTS  A    *
C*WEEKLY HYDROGRAPH AT THE WATERSHED OUTLET. TROPICS IS WRIT-*
C*TEN IN THE FORTRAN 77 LANGUAGE ON THE VAX COMPUTER SYSTEM    *
C*AT THE UNIVERSITY OF FLORIDA.                                *
C***************************************************************
C*                                                             *
C*   DECLARE THE DIFFERENT ARRAY SIZES OF THE MODEL            *
C***************************************************************
      COMMON /BLOCK1/ NFIRST(168),NLAST(168),RFIRST(168),
     $ RLAST(168)
      COMMON /BLOCK2/ RATE(55),WACS(55),SAV(55),DL(55),WIC(55)
     $ ,HKS(55)
      COMMON /BLOCK4/ POR(55),RMAXZD(55),WP(55),FC(55),
     $ DMAX(55),COEFF(55)
      COMMON /BLOCK5/ TMIN(7),TMAX(7),CSOLRA(7), RJLDAY(7)
      COMMON /BLOCK6/ KTIME(170),R(170)
      COMMON /BLOCK7/ NF3(168),NL3(168),RL3(168),RAINF3(168)
      COMMON /BLOCK8/ DT
      COMMON /BLOCK9/ ATEMP(7,24),TBAR(7),DTEM(7)
      COMMON /BLOCK10/ XT(100),YT(100),ARR(100),A1,ABDEVT
                  C  O  M  M  O  N    /  B  L  O  C  K  1  1  /
NTOTC,CONCEN(32),QQR(20),SURF(20),ARE1(32)
                  C  O  M  M  O  N    /  B  L  O  C  K  1  2  /
QH(168,55),QHH(168,55),QV(168,55),QVV(168,55)
      COMMON /BLOCK13/ INC(55,6)
      COMMON /BLOCK14/ NSC(55,2)
      CHARACTER*3 ANS1,ANS2,ANS3,ANS4
      CHARACTER*1 SSC(55,6)
      CHARACTER*20 BNAME
      INTEGER NUMB(55),JJ(55),JJ1(55),JJ2(55),NCH(55),
     $ NADJAC(55),NUME(55),NLAST2(168),NTIME(168),ITIMEX(168),
     $ NFIRS2(168),NTIME2(168), LEVEL(55),TB(168),TBNEW(168)
     $  ,CLASS(55),NCOUNT,IFLAG1(55),FLAG,NTIMEX(168),TIMEL(168),
     $  ITIME(168),TNEW(168),NT3(168),IPREV(168),M(10),N1F3(168),
     $ N1L3(168),N1T3(168)
      REAL ALPHA(55),AA(55),QI(168,55),D(55),SLOP(55),PCO(55),
     $ QBAR(168,55),QOVA(168,55),PRUNOF(168,55),RAINF2(168),
     $ GWR(168,55),THETA(168,55),H(168,55),RR(168),QOUTO(168),
     $ E0(168),QIO(55),C0(55),C1(55),TEMP(168),RF3(168),
     $  C2(55),RK(55),QCI(168,55),QC0(168,55),QOUT(168,55),XX(55)
     $  ,QTEMP(168,55),QOUTOT(168,55),QOL(168),VM(55),QOB(7),
     $  ERR1(168),ERR2(168),QREAD(168,55),HC(55),HWC(55),YY0(55),
     $ HTOTC(55),QQ0(55),WHY0(55), RLAST2(168),RAINF(168),NR,
                                                              $
RFIRS2(168),FILL(55,168),FIL(168,55),PARAM(55),RUNOF(55,168),
                                                              $
QSUM(168),GWAT(168,55),RAIN(168),HL(168),WW(55,6),DDC(55),
     $ THRG(55,168),SINTER(55,168),DSIN(55,168),EXCESS(55,168),
                                                              $
```

```
DE(55),ALL(55),RLEN(55),ALPHA3(55),SLPE(55),HCO(55),QOT(168,55),
     $ Y(168,55),ALPHA2,BETA,SMAX,DS(10),REYN(32,10),REYV(32),
                                                                 $
AVREYV(32),REYNOL,NU,BASAREA,RAINF1(168),R1L3(168),R1F3(168)
       DT=1
C**
C** READ THE DISCHARGES AT THE WATERSHED OUTLET FOR THE
C** WEEK OF STUDY; QOB(7) IS THE DISCHARGE MATRIX. SET
C** NTIMEX THE TIME COUNTER REQUIRED TO CONVERT THE DAILY
C** RAINFALL DATA INTO AN HOURLY RAINFALL DATA.
C**
C**    THIS PORTION OF THE PROGRAM READ AND PRINT TROPICS
C**    OUTPUT HEADINGS
C**    BNAME IS A MAXIMUM 20 CHARACTERS BASIN NAME
C**
       WRITE(*,*) ('READ BNAME: NAME OF BASIN OF INTEREST')
       READ(*,*) BNAME
       WRITE(*,*) ('READ BASIN AREA: BSAREA')
       READ(*,*) BSAREA
       OPEN(UNIT=7,FILE='TROPICS.OUT',STATUS='NEW')
       WRITE(7,880)
       WRITE(7,779)
       WRITE(7,881)
       WRITE(7,882)
       WRITE(7,883)
       WRITE(7,884) BNAME
       WRITE(7,885) BSAREA
       WRITE(7,*)
       WRITE(7,*)
       OPEN(UNIT=3,FILE='OLD.DAT',STATUS='OLD')
       READ(3,480) (QOB(K),K=1,7)
 3009  WRITE(*,482)
       WRITE(*,*)
       WRITE(*,*) ('READ PRINTING FLAG: IF1')
       READ(*,*) IF1
       IF(IF1.EQ.1)THEN
       WRITE(7,483)
       WRITE(7,481) (QOB(L),L=1,7)
       WRITE(7,*)
       WRITE(7,*)
       ELSEIF(IF1.EQ.0)THEN
       GOTO 3008
       ELSE
       WRITE(*,484)
       GOTO 3009
       ENDIF
3008   CONTINUE
       ID24=24
       NTIMEX(1)=24
       DO 101 I=2,7
       NTIMEX(I)=NTIMEX(1)+(I-1)*ID24
  101  CONTINUE
C** NOW READ THE RAINFALL DATA FROM UNIT 3 IN THE COMPUTER THE
C** FILE NAME IS RAIN.DAT
       OPEN(UNIT=3,FILE='RAIN.DAT',STATUS='OLD')
```

```
      READ(3,5) (RR(I),I=1,168)
3011  WRITE(*,562)
      WRITE(*,*)
      WRITE(*,*) ('READ PRINTING FLAG: IF2')
      READ(*,*) IF2
      IF(IF2.EQ.1)THEN
      WRITE(7,563)
      WRITE(7,561) (RR(I),I=1,168)
      WRITE(7,*)
      WRITE(7,*)
      ELSEIF(IF2.EQ.0)THEN
      GOTO 3010
      ELSE
      WRITE(*,564)
      GOTO 3011
      ENDIF
3010  CONTINUE
      DO 6 I=1,168
      ITIME(I)=I
 6    CONTINUE
      R(1)=0.0
      R(170)=0.0
      KTIME(1)=0
      KTIME(170)=0
      DO 7 K=2,169
      KTIME(K)=ITIME(K-1)
      R(K)=RR(K-1)/100
 7    CONTINUE
      WRITE(*,*) ('READ THE INTEREVENT TIME TL IN HOURS')
      READ(*,*) TL
      WRITE(*,*)
      WRITE(7,*) ('TIME(HR)=  '),('PRECIPITATION (M/HR)=')
      WRITE(7,*)
      CALL ORDER(NCOUNT,RAINF,NTIME)
      TB(NCOUNT+1)=TL
      TB(NCOUNT+2)=TL
      NFIRST(NCOUNT+1)=NFIRST(NCOUNT)
      NLAST(NCOUNT+1)=NLAST(NCOUNT)
      RFIRST(NCOUNT+1)=RFIRST(NCOUNT)
      RLAST(NCOUNT+1)=RLAST(NCOUNT)
      NFIRST(NCOUNT+2)=NFIRST(NCOUNT+1)
      NLAST(NCOUNT+2)=NLAST(NCOUNT+1)
      RFIRST(NCOUNT+2)=RFIRST(NCOUNT+1)
      RLAST(NCOUNT+2)=RLAST(NCOUNT+1)
      WRITE(7,*) ('NCOUNT='),NCOUNT
      WRITE(7,*)
      DO 8 J=1,NCOUNT
      TB(J)=NFIRST(J+1)-NLAST(J)
 8    CONTINUE
      IF(TB(1).LT.TL)THEN
      DO 9 J=2,NCOUNT+1
      IF(TB(J).GE.TL)K=J
      TBNEW(K)=TB(K)
      GOTO 10
 9    CONTINUE
 10    NLAST2(1)=NLAST(K)
       NFIRS2(1)=NFIRST(1)
       RFIRS2(1)=RFIRST(1)
       RLAST2(1)=RLAST(K)
C**CALCULATE RAINFALL VALUES FOR FIRST INDEPENDENT EVENT
       DO 11 KN=NFIRS2(1),NLAST2(1)
       RAINF2(KN)=RAINF(KN)
       NTIME2(KN)=NTIME(KN)
 11    CONTINUE
C** SUBROUTINE REORD ORDER THE RAINFALL DATA BY CREATING INDE-
C** INDEPENDENT EVENTS SEPARATED BY THE MINIMUM INTERINDEPEN-
C** CE TIME TL
       CALL REORD(K+1,TL,TB,NFIRS2,NLAST2,NTIME2,RLAST2,NTIME,
     $ RAINF,RAINF2,NCOUNT)
       ELSEIF(TB(1).GE.TL)THEN
       NLAST2(1)=NLAST(1)
       NFIRS2(1)=NFIRST(1)
       RFIRS2(1)=RFIRST(1)
       RLAST2(1)=RLAST(1)
       DO 12 II=NFIRS2(1),NLAST2(1)
       RAINF2(II)=RAINF(II)
       NTIME2(II)=NTIME(II)
   12  CONTINUE
       CALL REORD(2,TL,TB,NFIRS2,NLAST2,NTIME2,RLAST2,NTIME,
     $ RAINF,RAINF2,NCOUNT)
       ENDIF
       WRITE(7,*) ('THIS IS THE OUTPUT FROM REORD')
       WRITE(7,*) ('   TIME(Hr), RAIN(M/Hr)')
       WRITE(7,*)
       WRITE(7,*)
       DO 2050 J=1,NCOUNT+1
       DO 2060 K=NFIRS2(J),NLAST2(J)
       WRITE(7,*) NTIME2(K),RAINF2(K)
 2060  CONTINUE
 2050  CONTINUE
       WRITE(7,*)
       NEWC=0
       DO 13 J=1,NCOUNT+1
       IF((RAINF2(NFIRS2(J)).NE.0.0).AND.(RAINF2(NLAST2(J)).
     $ NE.0.0))THEN
       NEWC=NEWC+1
       NF3(NEWC)=NFIRS2(J)
       NL3(NEWC)=NLAST2(J)
       RL3(NEWC)=RLAST2(J)
       RF3(NEWC)=RFIRS2(J)
       TNEW(NEWC)=TBNEW(J)
       WRITE(7,*) ('NEWC='),NEWC
       DO 14 K=NF3(NEWC),NL3(NEWC)
       RAINF3(K)=RAINF2(K)
       NT3(K)=NTIME2(K)
   14  CONTINUE
       ENDIF
   13  CONTINUE
       WRITE(7,*)
       WRITE(7,*) ('RAIN AND TIME FOR PROGRAM')
```

```
      WRITE(7,*) ('     HR      M/HR')
      WRITE(7,*)
      DO 15 LL=1,NEWC
      DO 16 KK=NF3(LL),NL3(LL)
      WRITE(7,17) NT3(KK),RAINF3(KK)
   16 CONTINUE
   15 CONTINUE
C***************************************************************
C**   CALCULATE THE EVAPORATION EO USING THE PRIESTLY-TAYLOR *
C**   METHOD                                                 *
C***************************************************************
C** FIRST  CALCULATE  THE  HOURLY  TEMPERATURE  USING  SUBROUTINE
ATEMPE
      OPEN(UNIT=3,FILE='TEMP.DAT',STATUS='OLD')
      DO 107 K=1,7
      READ(3,18) TMIN(K),TMAX(K),CSOLRA(K),RJLDAY(K)
  107 CONTINUE
 3013 WRITE(*,662)
      WRITE(*,*)
      WRITE(*,*) ('READ PRINTING FILE: IF3')
      READ(*,*) IF3
      IF(IF3.EQ.1)THEN
      WRITE(7,663)
      DO 660 N=1,7
      WRITE(7,661) TMIN(N),TMAX(N),CSOLRA(N),RJLDAY(N)
 660  CONTINUE
      WRITE(7,*)
      WRITE(7,*)
      ELSEIF(IF3.EQ.0)THEN
      GOTO 3012
      ELSE
      WRITE(*,664)
      GOTO 3013
      ENDIF
3012  CONTINUE
      WRITE(7,*)
      WRITE(7,*)
      WRITE(7,*) ('TEMPERATURE VALUES')
      WRITE(7,*) ('IN DEGREES CENTIGRADES O C')
      WRITE(7,*)
      CALL ATEMPE(TEMP,NC)
C** NOW CALL THE EVAPOTRANSPIRATION ROUTINE
      WRITE(7,*)
      WRITE(7,*)
      WRITE(7,*) ('EVAPORATION VALUES IN M/DAY')
      WRITE(7,*)
      CALL EVAPO(EO)
C***************************************************************
C** INTRODUCING THE ELEMENTS INFORMATION FOR COMPONENTS       *
C** PROCESSES EVALUATION                                      *
C***************************************************************
      WRITE(*,*) ('READ THE TOTAL NUMBER OF ELEMENTS IN THE BA
     $ SIN :NEL')
      READ(*,*) NEL
      WRITE(*,*)  ('READ  TOTAL  NUMBER  OF  CHANNEL  SEGMENTS
NTOTC')
       READ(*,*) NTOTC
       WRITE(*,*) ('NUMBER OF ELEMENTS WITHOUT CHANNEL SEGMENT:
N3=?')
       READ(*,*) N3
       WRITE(*,*) ('NUMBER OF ELEMENTS WITH CHANNEL: N4=?')
       READ(*,*) N4
       DO 19 I=1,NEL
       WRITE(*,*) I
       WRITE(*,*) ('DO 2 CHANNEL ELEMENT DRAIN TO I ?')
       WRITE(*,*) ('READ ANSWER: YES OR NO')
       READ(*,2000) ANS
       IF(ANS.EQ.'YES')THEN
       WRITE(*,*) ('READ IPREV(I)')
       READ(*,*) IPREV(I)
       ENDIF
       WRITE(*,*) ('INPUT THE NUMBER OF ADJACENT ELEMENTS TO I,
     $ AND THE LEVEL OF I AND PRESS ENTER')
       READ(*,*) NUMB(I),LEVEL(I)
       IF(NUMB(I).EQ.10)GOTO 20
C**    ENTER THE INFORMATION RELATIVE TO THE NUMB(I) ELEMENTS
C**    ADJACENT TO ELEMENT I
       DO 21 KJ=1,NUMB(I)
       WRITE(*,*) KJ
       WRITE(*,*)  ('READ  THE  NUMBER  OF  THE  KJ  th  ELEMENT
ADJACENT
     $ TO I :INC(I,KJ) AND PRESS ENTER')
       READ(*,*) INC(I,KJ)
       WRITE(*,*)  ('INPUT  FLOW  STATUS  H=HORIZONTAL  FLOW,
V=VERTICAL
     $ FLOW AND PRESS ENTER')
       READ(*,2001) SSC(I,KJ)
       WRITE(*,*) ('FLOW WIDTH FROM ADJACENT ELEMENT=?')
       READ(*,*) WW(I,KJ)
  21   CONTINUE
       WRITE(*,*) ('ANSWER YES OR NO TO FOLLOWING QUESTIONS')
  20   WRITE(*,*) ('DOES ELEMENT I DRAIN TO LAKE ?')
       WRITE(*,*) ('READ ANSWER: YES OR NO')
       READ(*,2002) ANS1
       WRITE(*,*) ('DOES ELEMENT I HAVE A CHANNEL SEGMENT?')
       WRITE(*,*) ('READ ANSWER YES OR NO')
       READ(*,1900) ANS2
       IF((ANS1.EQ.'YES').AND.(ANS2.EQ.'NO'))THEN
       CLASS(I)=1
       ELSEIF((ANS1.EQ.'YES').AND.(ANS2.EQ.'NO'))THEN
       CLASS(I)=2
       ELSEIF((ANS1.EQ.'NO').AND.(ANS2.EQ.'YES'))THEN
       CLASS(I)=3
       ELSEIF((ANS1.EQ.'NO').AND.(ANS2.EQ.'NO'))THEN
       CLASS(I)=4
       ELSE
       WRITE(*,*)('CHECK INPUTS ANS1 AND ANS2 FOR MISTAKES')
       GOTO 20
       ENDIF
C**
```

```
C** NOTE: SUMMARY OF THE ELEMENTS CLASSIFICATION IN CLASSES FROM
C**        1 THROUGH 4
C** CLASS(I)=1 : MEANS THAT THE ELEMENT DRAINS TO A RESERVOIR
AND
C**                 CONTAINS AT LEAST 1 CHANNEL SEGMENT.
C** CLASS(I)=2 : MEANS THAT THE ELEMENT DRAINS TO A LAKE BUT HAS
C**                 NO CHANNEL SEGMENT CROSSING IT.
C** CLASS(I)=3 : MEANS THAT THE ELEMENT DOESN'T DRAIN TO A LAKE
C**                 OR RESERVOIR BUT HAS A CHANNEL SEGMENT
C** CLASS(I)=4 : MEANS THAT THE ELEMENT DOESN'T DRAIN TO A LAKE
C**                 AND HAS NO CHANNEL SEGMENT.
C**
      IF(CLASS(I).EQ.1)THEN
      WRITE(*,*) ('NUMBER OF CHANNEL SEGMENTS IN ELEMENT I= ?')
  22  READ(*,*) NUME(I)
      IF(NUME(I).EQ.1)THEN
      WRITE(*,*) ('ELEMENT ONLY HAS 1 CHANNEL SEGMENT')
      WRITE(*,*) ('READ CHANNEL #')
      READ(*,*) JJ(I)
      CALL CHAN(NADJAC(JJ(I)),JJ(I),NCH(JJ(I)),NSC(JJ(I),1),
     $ NSC(JJ(I),2))
      ELSEIF(NUME(I).EQ.2)THEN
      WRITE(*,*) ('FIRST CHANNEL SEGMENT # =?')
      READ(*,*) JJ1(I)
                                             C    A    L    L
CHAN(NADJAC(JJ1(I)),JJ1(I),NCH(JJ1(I)),NSC(JJ1(I),1),
     $ NSC(JJ1(I),2))
      WRITE(*,*) ('2nd CHANNEL # =?')
      READ(*,*) JJ2(I)
                                             C    A    L    L
CHAN(NADJAC(JJ2(I)),JJ2(I),NCH(JJ2(I)),NSC(JJ2(I),1),
     $ NSC(JJ2(I),2))
      ELSE
      WRITE(*,*) ('NUME(I) CAN ONLY BE 1 OR 2, RETRY')
      GOTO 22
      ENDIF
      ELSEIF(CLASS(I).EQ.3)THEN
      WRITE(*,*) ('HOW MANY CHANNELS IN ELEMENT?')
      READ(*,*) NUME(I)
      IF(NUME(I).EQ.1)THEN
      WRITE(*,*) ('ELEMENT IS A 1 CHANNEL SEGMENT ELEMENT')
      WRITE(*,*) ('READ CHANNEL ELEMENT #')
      READ(*,*) JJ(I)
      CALL CHAN(NADJAC(JJ(I)),JJ(I),NCH(JJ(I)),NSC(JJ(I),1),
     $ NSC(JJ(I),2))
      WRITE(*,*) ('IS JJ(I) AN OUTLET ELEMENT ?')
      WRITE(*,*) ('READ ANSWER: YES OR NO')
      READ(*,2003) ANS3
      IF(ANS3.EQ.'NO')THEN
      IFLAG1(JJ(I))=0
      ELSEIF(ANS3.EQ.'YES')THEN
      IFLAG1(JJ(I))=1
      ENDIF
      ELSEIF(NUME(I).EQ.2)THEN
      WRITE(*,*) ('FIRST CHANNEL SEGMENT # =?')
      READ(*,*) JJ1(I)
                                        C    A    L    L
CHAN(NADJAC(JJ1(I)),JJ1(I),NCH(JJ1(I)),NSC(JJ1(I),1),
     $ NSC(JJ1(I),2))
      WRITE(*,*) ('2nd CHANNEL # =?')
      READ(*,*) JJ2(I)
                                        C    A    L    L
CHAN(NADJAC(JJ2(I)),JJ2(I),NCH(JJ2(I)),NSC(JJ2(I),1),
     $ NSC(JJ2(I),2))
      WRITE(*,*) ('IS 2nd CHANNEL AN OUTLET CHANNEL?')
      WRITE(*,*) ('READ ANSWER: YES OR NO')
      READ(*,2004) ANS4
      IF(ANS4.EQ.'NO')THEN
      IFLAG1(JJ2(I))=0
      ELSEIF(ANS4.EQ.'YES')THEN
      IFLAG1(JJ2(I))=1
      ENDIF
      ENDIF
      ENDIF
 19   CONTINUE
C**
C**  READ THE OVERLAND FLOW INPUT FILE
C**
 2100 WRITE(*,*) ('READ EQUIVALENT SAND ROUGHNESS VALUE: EKAY')
      READ(*,*) EKAY
      WRITE(*,*) ('READ THE DRAG COEFFICIENT VALUE : CD')
      READ(*,*) CD
      OPEN(UNIT=3,FILE='OVL.DAT',STATUS='OLD')
      DO 61 IL=1,NEL
      READ(3,150) WHY0(IL),AA(IL),SLPE(IL),ALPHA3(IL)
 61   CONTINUE
C**
C** INITIALIZE THE OUTFLOW MATRIX QOUTOT(168,NEL)
C**
      DO 102 J0=1,NTIMEX(1)
      QREAD(J0,NEL)=QOB(1)/24
 102  CONTINUE
      DO 103 JL=1,6
      KX=JL
      DO 104 K=NTIMEX(KX),NTIMEX(KX+1)
      QREAD(K,NEL)=QOB(KX+1)/24
 104  CONTINUE
 103  CONTINUE
C**
C** CALCULATE QUBAR : THE AVERAGE DISCHARGE
C**
      QUTO=0.0
      DO 105 KK=1,168
      QUTO=QUTO+QREAD(KK,NEL)
 105  CONTINUE
      QUBAR=QUTO/168
C*************************************************************
C**IN THE FOLLOWING STEPS, THE MODEL CALCULATES THE COMPONENT
C**PROCESSES SUCH AS INTERCEPTION, INFILTRATION ,AND DEPRESSION
C** STORAGE.
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C*************************************************************
C**           CALCULATE THE INTERCEPTION
C**           **************************
      OPEN(UNIT=3,FILE='INTER1.DAT',STATUS='OLD')
      WRITE(*,*) ('THE NUMBER OF DIAMETER CLASSES NL=?')
      READ(*,*) NL
      WRITE(*,*) ('READ INTERCEPTION COEFFICIENT ALPHA2')
      READ(*,*) ALPHA2
      WRITE(*,*) ('READ INTERCEPTION COEFFICIENT BETA')
      READ(*,*) BETA
      WRITE(*,*) ('READ MAXIMUM INTERCEPTION VALUE')
      READ(*,*) SMAX
      READ(3,23,END=24) (ALL(L),L=1,NEL)
   24 CONTINUE
 3015 WRITE(*,762)
      WRITE(*,*)
      WRITE(*,*) ('READ PRINTING FLAG: IF4')
      READ(*,*) IF4
      IF(IF4.EQ.1)THEN
      WRITE(7,763)
      WRITE(7,761) (ALL(K),K=1,NEL)
      WRITE(7,*)
      WRITE(7,*)
      ELSEIF(IF4.EQ.0)THEN
      GOTO 3014
      ELSE
      WRITE(7,764)
      GOTO 3015
      ENDIF
 3014 CONTINUE
      OPEN(UNIT=3,FILE='INTER2.DAT',STATUS='OLD')
      DO 2200 KF=1,NL
      READ(3,2300) DS(KF),M(KF)
 2200 CONTINUE
 3017 WRITE(*,772)
      WRITE(*,*)
      WRITE(*,*) ('READ PRINTING FLAG: IF5')
      READ(*,*) IF5
      IF(IF5.EQ.1)THEN
      WRITE(7,773)
      DO 770 L=1,NL
      WRITE(7,771) DS(L),M(L)
  770 CONTINUE
      WRITE(7,*)
      WRITE(7,*)
      ELSEIF(IF5.EQ.0)THEN
      GOTO 3016
      ELSE
      WRITE(*,774)
      GOTO 3017
      ENDIF
 3016 CONTINUE
C** READ INFILTRATION AND DEPRESSION STORAGE DATA
      WRITE(*,*) ('READ FIRST DEPRESSION STORAGE COEFFICENT:
AB')
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```
      READ(*,*) AB
      WRITE(*,*) ('READ  SECOND DEPRESSION STORAGE COEFIICIENT:
BA')
      READ(*,*) BA
      OPEN(UNIT=3,FILE='INFDSP.DAT',STATUS='OLD')
      DO 70 L=1,NEL
                         READ(3,242)
RATE(L),WACS(L),SAV(L),DL(L),WIC(L),HKS(L),DE(L)
  70  CONTINUE
 3019 WRITE(*,782)
      WRITE(*,*)
      WRITE(*,*) ('READ PRINTING FLAG: IF6')
      READ(*,*) IF6
      IF(IF6.EQ.1)THEN
      WRITE(7,783)
      DO 780 L=1,NEL
                         WRITE(7,781)
RATE(L),WACS(L),SAV(L),DL(L),WIC(L),HKS(L),DE(L)
 780  CONTINUE
      WRITE(7,*)
      WRITE(7,*)
      ELSEIF(IF6.EQ.0)THEN
      GOTO 3018
      ELSE
      WRITE(*,784)
      GOTO 3019
      ENDIF
 3018 CONTINUE
      DO 25 I=1,NEL
      DC=DCOMP(ALPHA2,BETA,ALL(I),NL,DS,M)
      DDC(I)=DC
      WRITE(7,*) ('FOR ELEMENT # ='),I
      WRITE(7,*)
      WRITE(7,*) ('THE CANOPY DENSITY=')
      WRITE(7,*) DDC(I)
      WRITE(7,*)
      WRITE(7,*) ('THE COMPUTED THROUGHFALL VALUES=')
      WRITE(7,*)
      WRITE(7,*) ('  TIME(Hr)   THROUGHFALL (M/Hr)')
      WRITE(7,*)
      CALL INTERP(I,NEWC,SMAX,DDC(I),THRG)
      WRITE(7,*)
      WRITE(7,*) ('THE COMPUTED INFILTRATION VALUES=')
      WRITE(7,*) ('  TIME (HR)   EXCESS(M/HR)   INFILT(M/HR)')
      WRITE(7,*)
C**         CALCULATE THE INFILTRATION
C**         ***************************
      CALL INFILT(I,NEWC,NT3,TNEW,THRG,FILL,EXCESS)
      WRITE(7,*)
C**   CALCULATE THE DEPRESSION STORAGE AND OBTAIN THE RAIN-
C**   FALL EXCESS FROM EACH ELEMENT
      CALL DEPST(I,EXCESS,NT3,NEWC,DE(I),RUNOF)
   25 CONTINUE
      WRITE(7,*)
C**   NOW GET THE TRANSPOSE OF THE INFILTRATION AND THE
```

```
C**    THE RUNOFF MATRIXES FOR FLOW CALCULATIONS.
       DO 26 J=1,NEWC
       DO 27 K=NF3(J),NL3(J)
       DO 28 I=1,NEL
       PRUNOF(K,I)=RUNOF(I,K)
       FIL(K,I)=FILL(I,K)
   28  CONTINUE
   27  CONTINUE
   26  CONTINUE
       WRITE(7,*)
C** OPEN THE CHANNEL INPUT FILE AND CALCULATE THE MUSKINGUM
C** COEFFICIENTS
       OPEN(UNIT=3,FILE='CHAN1.DAT',STATUS='OLD')
       DO 130 K=1,NTOTC
       READ(3,240) RLEN(K),HTOTC(K),XX(K),SLOP(K)
  130  CONTINUE
 3025  WRITE(*,872)
       WRITE(*,*)
       WRITE(*,*) ('READ THE PRINTING FLAG: IF9')
       READ(*,*) IF9
       IF(IF9.EQ.1)THEN
       WRITE(7,873)
       DO 870 N=1,NTOTC
       WRITE(7,871) RLEN(N),HTOTC(N),XX(N),SLOP(N)
  870  CONTINUE
       WRITE(7,*)
       WRITE(7,*)
       ELSEIF(IF9.EQ.0)THEN
       GOTO 3024
       ELSE
       WRITE(*,874)
       GOTO 3025
       ENDIF
 3024  CONTINUE
C**
C** CAN VM,HWC,YY0,QQ0,AND HC BE DIRECTLY INPUT TO THE MODEL
C** IF NOT, READ THE CONCENTRATION, THE DISCHARGE VALUE QQR
C** AND THE AREA VALUES NECESARY TO CALCULATE THE REGRESSION
C** COEFFICIENTS GAMMA AND LAMBDA. ALSO READ THE NUMBER NNUM
C** OF QQR VALUES. READ  FLAG, IF FLAG=1 THE VALUES LISTED
C** ABOVE ARE GIVEN AND ARE INPUT BY READING THE DATA FROM
C** FILE CHAN2.DAT. IF FLAG=2, READ THE CONCENTRATION
C** CONCEN, THE DISCHARGE QQR AND THE AREA SURF TO COMPUTE
C** THE REGRESSION COEFFICIENTS. IF FLAG IS DIFFERENT FROM
C** THE VALUES MENTIONED REREAD THE FLAG.
C**
       WRITE(*,*) ('INPUT CHANNEL INFORMATION')
  135  WRITE(*,*) ('READ FLAG; FLAG SHOULD BE 1 OR 2')
       READ(*,*) FLAG
       WRITE(7,*)
       WRITE(*,*) ('READ THE NUMBER OF REGRESSION POINTS: NREG')
       READ(*,*) NREG
       IF(FLAG.EQ.1)THEN
       OPEN(UNIT=3,FILE='CHAN2.DAT',STATUS='OLD')
       DO 140 K=1,NTOTC
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```
      READ(3,270) VM(K),HC(K),QQ0(K),YY0(K),HWC(K)
 140  CONTINUE
      ELSEIF(FLAG.EQ.2)THEN
      OPEN(UNIT=3,FILE='REG.DAT',STATUS='OLD')
      DO 279 L=1,NREG
      READ(3,280) QQR(L),SURF(L)
 279  CONTINUE
      OPEN(UNIT=3,FILE='CHAN3.DAT', STATUS='OLD')
      DO 289 JL=1,NTOTC
      READ(3,290) CONCEN(JL),ARE1(JL)
 289  CONTINUE
      WRITE(7,*)
C**  CALL SUBROUTINE CHANIP TO CALCULATE CHANNEL PARAMETERS
      CALL CHANIP(NREG,HTOTC,HC,VM,QQ0,YY0,HWC)
      ELSE
      WRITE(*,*) ('WRONG FLAG VALUE : REM FLAG=1 OR 2')
      GOTO 135
      ENDIF
      WRITE(7,*)
C**
C** NOW CALCULATE THE MUSKINGUM COEFFICIENTS
C**
      DO 131 NJ=1,NTOTC
      RK(NJ)=(RLEN(NJ)/(VM(NJ)*3600))*(3.0/5.0)
      D(NJ)=RK(NJ)-RK(NJ)*XX(NJ)+0.5*DT
      C0(NJ)=(-RK(NJ)*XX(NJ)+0.5*DT)/D(NJ)
      C1(NJ)=(RK(NJ)+0.5*DT)/D(NJ)
      C2(NJ)=(RK(NJ)-RK(NJ)*XX(NJ)-0.5*DT)/D(NJ)
  131 CONTINUE
      DO 177 I=1,NEL
      POR(I)=WACS(I)
  177 CONTINUE
C**
C** ESTIMATING THE REYNOLDS NUMBER
C**
      SUMTMP=0.0
      DO 3000 I=1,168
      SUMTMP=SUMTMP+TEMP(I)
 3000 CONTINUE
      AVTMP=SUMTMP/168
      NU=0.130E-5/(((43.9+1.8*AVTMP)/93.9)**1.5)
      DO 3001 K=1,NTOTC
      DO 3002 J=1,10
      REYN(K,J)=VM(K)*DS(J)/NU
 3002 CONTINUE
 3001 CONTINUE
      DO 3005 L=1,NTOTC
      REYV(L)=0.0
      DO 3006 N=1,10
      REYV(L)=REYV(L)+REYN(L,N)
 3006 CONTINUE
      AVREYV(L)=REYV(L)/10
 3005 CONTINUE
      SUM=0.0
      DO 3007 L=1,NTOTC
      SUM=SUM+AVREYV(L)
 3007 CONTINUE
      REYNOL=SUM/NTOTC
      CDOLD=CD
      IF(REYNOL.LT.1.0E+5)THEN
      CD=CDOLD
      ELSE
      CD=0.3
      ENDIF
C** READ THE GROUNDWATER FLOW INPUT FILE
C**
      OPEN(UNIT=3,FILE='GRDWAT.DAT',STATUS='OLD')
      DO 110 I=1,NEL
      READ(3,120) PCO(I),HCO(I),WP(I),FC(I),COEFF(I),
     $ RMAXZD(I),DMAX(I)
 110  CONTINUE
C**
C***  READ THE LAKE INPUT FILE INLAKE.DAT WHEN THERE IS A LAKE
C**  WITHIN THE WATERSHED.
C**
  301 WRITE(*,*) ('READ LAKE FLAG LFLAG')
      WRITE(*,*) ('LFLAG=?')
      READ(*,*) LFLAG
      IF(LFLAG.EQ.0)THEN
      WRITE(*,*) ('THERE IS NO LAKE OR RESERVOIR IN THE BASIN')
      GOTO 302
      ELSEIF(LFLAG.EQ.1)THEN
      OPEN(UNIT=3,FILE='INLAKE.DAT',STATUS='OLD')
      READ(3,243,END=244) APL,AL,SLAKE,NR
 244  CONTINUE
      ELSE
      WRITE(*,*) ('LFLAG IS EQUAL TO 0 OR 1')
      GOTO 301
      ENDIF
 302  CONTINUE
C************************************************************
C**NOW CALCULATE THE FLOW COMPONENTS. THE FIRST OF SUCH IS THE
C** OVERLAND FLOW SUBROUTINE
C************************************************************
C**   INITIALIZE OVERLAND FLOW AND GROUNDWATER FLOW MATRIXES
C**       IN THE SAME LOOP
C************************************************************
      DO 30 J=1,NEWC
      KI=NF3(J)-1
      DO 31 I=1,NEL
      QI(KI,I)=0.0
      QOVA(KI,I)=0.0
      Y(KI,I)=0.000005
      QH(KI,I)=0.0
      QHH(KI,I)=0.0
      QV(KI,I)=0.0
      QVV(KI,I)=0.0
      QBAR(KI,I)=0.0
      IF(NUME(I).EQ.1)THEN
      H(KI,JJ(I))=HC(JJ(I))
      THETA(KI,JJ(I))=WIC(I)
      QCO(KI,JJ(I))=QQ0(JJ(I))
      QCI(KI,JJ(I))=QQ0(JJ(I))
      QOUT(KI,JJ(I))=QQ0(JJ(I))
      ELSEIF(NUME(I).EQ.2)THEN
      H(KI,JJ1(I))=HC(JJ1(I))
      H(KI,JJ2(I))=HC(JJ2(I))
      THETA(KI,JJ1(I))=WIC(I)
      THETA(KI,JJ2(I))=WIC(I)
      QCO(KI,JJ1(I))=QQ0(JJ1(I))
      QCO(KI,JJ2(I))=QQ0(JJ2(I))
      QCI(KI,JJ1(I))=QQ0(JJ1(I))
      QCI(KI,JJ2(I))=QQ0(JJ2(I))
      QOUT(KI,JJ1(I))=QQ0(JJ1(I))
      QOUT(KI,JJ2(I))=QQ0(JJ2(I))
      ENDIF
   31 CONTINUE
   30 CONTINUE
C** NOW CALL THE OVERLAND FLOW SUBROUTINE : OVLAND*********
      DO 32 J=1,NEWC
      DO 33 K=NF3(J),NL3(J)
      DO 34 I=1,NEL
      PARAM(I)=0.0
      DO 35 KN=1,10
      PARAM(I)=PARAM(I)+M(KN)*DS(KN)*CD
   35 CONTINUE
                                             C    A    L    L
OVLAND(I,K,QI(K-1,I),NUMB(I),PARAM(I),SSC,AA,WW,ALL(I)
                                                               $
,PRUNOF(K,I),EKAY,ALPHA3(I),Y(K-1,I),WHY0(I),CLASS(I),QI(K,I)
     $ ,QBAR(K,I),LEVEL(I),SLPE(I),Y(K,I),QOVA(K,I))
C**********************************************************
C** IN THE NEXT STEP, THE MODEL CALCULATES GROUNDWATER FLOW
C**             BY USING SUBROUTINE GWATER
C** *******************************************************
      IF(NUME(I).EQ.1)THEN
      CALL  GWATER(I,K,E0(K),JJ(I),WACS(I),HTOTC(JJ(I)),FIL(K,I)
     $ ,POR(I),H(K-1,JJ(I)),WIC(I),THETA(K-1,JJ(I)),FC(I),
     $ WP(I),HKS(I),HCO(I),PCO(I),RMAXZD(I),DMAX(I),COEFF(I),
     $ THETA(K,JJ(I)),H(K,JJ(I)),GWAT(K,JJ(I)))
      GWR(K,I)=GWAT(K,JJ(I))
      ELSEIF(NUME(I).EQ.2)THEN
      CALL GWATER(I,K,E0(K),JJ1(I),WACS(I),HTOTC(JJ1(I)),
     $ FIL(K,I),POR(I),H(K-1,JJ1(I)),WIC(I),THETA(K-1,JJ1(I)),
                                                               $
FC(I),WP(I),HKS(I),HCO(I),PCO(I),RMAXZD(I),DMAX(I),COEFF(I),
     $ THETA(K,JJ1(I)),H(K,JJ1(I)),GWAT(K,JJ1(I)))
      CALL GWATER(I,K,E0(K),JJ2(I),WACS(I),HTOTC(
                                                               $
JJ2(I)),FIL(K,I),POR(I),H(K-1,JJ2(I)),WIC(I),THETA(K-1,JJ2(I)),
                                                               $
FC(I),WP(I),HKS(I),HCO(I),PCO(I),RMAXZD(I),DMAX(I),COEFF(I),
     $ THETA(K,JJ2(I)),H(K,JJ2(I)),GWAT(K,JJ2(I)))
      GWR(K,I)=GWAT(K,JJ1(I))+GWAT(K,JJ2(I))
      ENDIF
```

```
C*************************************************************
C**THE CHANNEL FLOW ROUTING IS THE MOST DELICATE SECTION OF THE
C**  PROGRAM. IT IS PERFORMED AT THE SAME TIME WITH THE LAKE OR
C**  RESERVOIR FLOW ROUTINE CALLED LROUTE. SUBROUTINE MUSKIN IS
C**  USED FLOW SIMULATION BASED ON THE MUSKINGUM METHOD OF FLOW
C**  ROUTING.
C*************************************************************

IF((CLASS(I).EQ.1).AND.(NUME(I).EQ.1).AND.(NADJAC(JJ(I)).EQ.
     $ 1))THEN
        LC=LC+1
        QCI(K,JJ(I))=QOUT(K,NCH(JJ(I)))
        CALL  MUSKIN(C0(JJ(I)),C1(JJ(I)),C2(JJ(I)),QCI(K-1,JJ(I)),
                                                               $
QCI(K,JJ(I)),QOVA(K,I),GWR(K,I),QC0(K-1,JJ(I)),QC0(K,JJ(I)),
     $ QOUT(K,JJ(I)))
        QOT(K,LC)=QOUT(K,JJ(I))
        CALL ADD(QSUM(K-1),QOT(K,LC),0.0,QSUM(K))
        IF((KC.GT.N3).AND.(LC.GT.N4))THEN
        CALL LROUTE(QSUM(K-1),QSUM(K),HL(K-1),APL,AL,SLAKE,NR,
     $ RF3(K-1),RF3(K),E0(K-1),E0(K),HL(K),QOL(K))
        ELSE
        GOTO 40
        ENDIF
        ELSEIF((CLASS(I).EQ.1).AND.(NUME(I).EQ.1).AND.(NADJAC(
     $ JJ(I)).EQ.2))THEN
        LC=LC+1
        QCI(K,JJ(I))=QC0(K,NSC(JJ(I),1))+QC0(K,NSC(JJ(I),2))+
     $ QOVA(K,IPREV(I))+GWR(K,IPREV(I))
        CALL  MUSKIN(C0(JJ(I)),C1(JJ(I)),C2(JJ(I)),QCI(K-1,JJ(I)),
                                                               $
QCI(K,JJ(I)),QOVA(K,I),GWR(K,I),QC0(K-1,JJ(I)),QC0(K,JJ(I)),
     $ QOUT(K,JJ(I)))
        IF((KC.GT.N3).AND.(LC.GT.N4))THEN
        CALL LROUTE(QSUM(K-1),QSUM(K),HL(K-1),APL,AL,SLAKE,NR,
     $ RF3(K-1),RF3(K),E0(K-1),E0(K),HL(K),QOL(K))
        ELSE
        GOTO 40
        ENDIF
        ELSEIF((CLASS(I).EQ.1).AND.(NUME(I).EQ.2))THEN
        LC=LC+2
C***    ROUTE FLOW THROUGH THE FIRST CHANNEL SEGMENT :JJ1(I)
        IF(NADJAC(JJ1(I)).EQ.1)THEN
        QCI(K,JJ1(I))=QOUT(K,NCH(JJ1(I)))
                                           C    A    L    L
MUSKIN(C0(JJ1(I)),C1(JJ1(I)),C2(JJ1(I)),QCI(K-1,JJ1(I
                                                               $
)),QCI(K,JJ1(I)),QOVA(K,I),GWR(K,I),QC0(K-1,JJ1(I)),QC0(K,JJ1(I)
     $ ),QOUT(K,JJ1(I)))
        ELSEIF(NADJAC(JJ1(I)).EQ.2)THEN
        QCI(K,JJ1(I))=QC0(K,NSC(JJ1(I),1))+QC0(K,NSC(JJ1(I),2))+
     $ QOVA(K,IPREV(I))+GWR(K,IPREV(I))
                                           C    A    L    L
MUSKIN(C0(JJ1(I)),C1(JJ1(I)),C2(JJ1(I)),QCI(K-1,JJ1(I
                                                               $
)),QCI(K,JJ1(I)),QOVA(K,I),GWR(K,I),QCO(K-1,JJ1(I)),QCO(K,
     $ JJ1(I)),QOUT(K,JJ1(I)))
        ENDIF
C**     ROUTE FLOW THROUGH SECOND CHANNEL SEGMENT : JJ2(I)
        IF(NADJAC(JJ2(I)).EQ.1)THEN
        QCI(K,JJ2(I))=QOUT(K,NCH(JJ2(I)))
                                                 C     A     L     L
MUSKIN(CO(JJ2(I)),C1(JJ2(I)),C2(JJ2(I)),QCI(K-1,JJ2(I
                                                                  $
)),QCI(K,JJ2(I)),QOVA(K,I),GWR(K,I),QCO(K-1,JJ2(I)),QCO(K,JJ2(I)
     $ ),QOUT(K,JJ2(I)))
        ELSEIF(NADJAC(JJ2(I)).EQ.2)THEN
        QCI(K,JJ2(I))=QCO(K,NSC(JJ2(I),1))+QCO(K,NSC(JJ2(I),2))+
     $ QOVA(K,IPREV(I))+GWR(K,IPREV(I))
                                                 C     A     L     L
MUSKIN(CO(JJ2(I)),C1(JJ2(I)),C2(JJ2(I)),QCI(K-1,JJ2(I
                                                                  $
)),QCI(K,JJ2(I)),QOVA(K,I),GWR(K,I),QCO(K-1,JJ2(I)),QCO(K,JJ2(I)
     $ ),QOUT(K,JJ2(I)))

QTEMP(K,I)=QOUT(K,JJ1(I))+QOUT(K,JJ2(I))+QOVA(K,I)+GWR(K,I)
        QOT(K,LC)=QTEMP(K,I)
        CALL ADD(QSUM(K-1),QOT(K,LC),0.0,QSUM(K))
        IF((KC.GT.N3).AND.(LC.GT.N4))THEN
        CALL LROUTE(QSUM(K-1),QSUM(K),HL(K-1),APL,AL,SLAKE,NR,
     $ RF3(K-1),RF3(K),EO(K-1),EO(K),HL(K),QOL(K))
        ELSE
        GOTO 40
        ENDIF
        ENDIF
        ENDIF
        IF(CLASS(I).EQ.2)THEN
        KC=KC+1
        CALL ADD(QSUM(K-1),0.0,QOVA(K,I),QSUM(K))
        IF((KC.GE.N3).AND.(LC.GE.N4))THEN
        CALL LROUTE(QSUM(K-1),QSUM(K),HL(K-1),APL,AL,SLAKE,NR,
     $ RF3(K-1),RF3(K),EO(K-1),HL(K),QOL(K))
        ELSE
        GOTO 40
        ENDIF
        ENDIF

IF((CLASS(I).EQ.3).AND.(NUME(I).EQ.1).AND.(NADJAC(JJ(I)).EQ.
     $ 1))THEN
        QCI(K,JJ(I))=QOUT(K,NCH(JJ(I)))
        CALL  MUSKIN(CO(JJ(I)),C1(JJ(I)),C2(JJ(I)),QCI(K-1,JJ(I)),
                                                                  $
QCI(K,JJ(I)),QOVA(K,I),GWR(K,I),QCO(K-1,JJ(I)),QCO(K,JJ(I)
     $ ),QOUT(K,JJ(I)))
        QOUTOT(K,I)=QOUT(K,JJ(I))

ELSEIF((CLASS(I).EQ.3).AND.(NUME(I).EQ.1).AND.(NADJAC(JJ(I))
     $ .EQ.2))THEN

QCI(K,JJ(I))=QCO(K,NSC(JJ(I),1))+QCO(K,NSC(JJ(I),2))+QOVA(K
    $ ,IPREV(I))+GWR(K,IPREV(I))
      CALL  MUSKIN(C0(JJ(I)),C1(JJ(I)),C2(JJ(I)),QCI(K-1,JJ(I)),
                                                               $
QCI(K,JJ(I)),QOVA(K,I),GWR(K,I),QC0(K-1,JJ(I)),QC0(K,JJ(I)),
    $ QOUT(K,JJ(I)))
      QOUTOT(K,I)=QOUT(K,JJ(I))

ELSEIF((CLASS(I).EQ.3).AND.(NUME(I).EQ.1).AND.(IFLAG1(JJ(I))
    $ .EQ.1))THEN
      QCI(K,JJ(I))=QOL(K)
      CALL  MUSKIN(C0(JJ(I)),C1(JJ(I)),C2(JJ(I)),QCI(K-1,JJ(I)),
                                                               $
QCI(K,JJ(I)),QOVA(K,I),GWR(K,I),QC0(K-1,JJ(I)),QC0(K,JJ(I)
    $ ),QOUT(K,JJ(I)))
      QOUTOT(K,I)=QOUT(K,JJ(I))
      ELSEIF((CLASS(I).EQ.3).AND.(NUME(I).EQ.2))THEN
C***  ROUTE FLOW THROUGH THE FIRST CHANNEL SEGMENT : JJ1(I)
      IF(NADJAC(JJ1(I)).EQ.1)THEN
      QCI(K,JJ1(I))=QOUT(K,NCH(JJ1(I)))
                                          C    A    L    L
MUSKIN(C0(JJ1(I)),C1(JJ1(I)),C2(JJ1(I)),QCI(K-1,JJ1(I))
                                                               $
,QCI(K,JJ1(I)),QOVA(K,I),GWR(K,I),QC0(K-1,JJ1(I)),QC0(K,JJ1(I)),

    $ QOUT(K,JJ1(I)))
      ELSEIF(NADJAC(JJ1(I)).EQ.2)THEN
      QCI(K,JJ1(I))=QC0(K,NSC(JJ1(I),1))+QC0(K,NSC(JJ1(I),2))+
    $ QOVA(K,IPREV(I))+GWR(K,IPREV(I))
      CALL  MUSKIN(C0(JJ1(I)),C1(JJ1(I)),C2(JJ1(I)),QCI(K-1,JJ1(
                                                               $
I)),QCI(K,JJ1(I)),QOVA(K,I),GWR(K,I),QC0(K-1,JJ1(I)),QC0(K,JJ1(I
    $ )),QOUT(K,JJ1(I)))
      ENDIF
C**   ROUTE FLOW THROUGH 2ND CHANNEL SEGMENT :JJ2(I)
      IF(NADJAC(JJ2(I)).EQ.1)THEN
      QCI(K,JJ2(I))=QOUT(K,NCH(JJ2(I)))
      CALL  MUSKIN(C0(JJ2(I)),C1(JJ2(I)),C2(JJ2(I)),QCI(K-1,JJ2(
                                                               $
I)),QCI(K,JJ2(I)),QOVA(K,I),GWR(K,I),QC0(K-1,JJ2(I)),QC0(K,JJ2(
    $ I)),QOUT(K,JJ2(I)))
      ELSEIF(NADJAC(JJ2(I)).EQ.2.AND.IFLAG1(JJ2(I)).EQ.0)THEN
      QCI(K,JJ2(I))=QC0(K,NSC(JJ2(I),1))+QC0(K,NSC(JJ2(I),2))+
    $ QOVA(K,IPREV(I))+GWR(K,IPREV(I))
      CALL  MUSKIN(C0(JJ2(I)),C1(JJ2(I)),C2(JJ2(I)),QCI(K-1,JJ2(
    $ I)),QCI(K,JJ2(I)),QOVA(K,I),GWR(K,I),QC0(K-1,JJ2(I)),QC0
    $  (K,JJ2(I)),QOUT(K,JJ2(I)))
      ELSEIF(NADJAC(JJ2(I)).EQ.2.AND.IFLAG1(I).EQ.1)THEN
      QCI(K,JJ2(I))=QOL(K)
      CALL  MUSKIN(C0(JJ2(I)),C1(JJ2(I)),C2(JJ2(I)),QCI(K-1,JJ2(
                                                               $
I)),QCI(K,JJ2(I)),QOVA(K,I),GWR(K,I),QC0(K-1,JJ2(I)),QC0(K,
    $ JJ2(I)),QOUT(K,JJ2(I)))
      ENDIF
      QOUTOT(K,I)=QOUT(K,JJ1(I))+QOUT(K,JJ2(I))
      ENDIF
      IF(CLASS(I).EQ.4)THEN
      QOUTOT(K,I)=QOVA(K,I)
      GOTO 40
      ENDIF
   40 CONTINUE
   34 CONTINUE
   33 CONTINUE
   32 CONTINUE
C**
C** PRINT THE OVERLAND FLOW INPUT DATA AND THE GROUNDWATER INPUT
C** DATA WITH THE OUTPUT
C**
C**
C** WRITING THE OVERLAND FLOW INPUT DATA ON THE OUTPUT FILE
C**
 3021 WRITE(*,792)
      WRITE(*,*)
      WRITE(*,*) ('READ THE PRINTING FLAG: IF7')
      READ(*,*) IF7
      IF(IF7.EQ.1)THEN
      WRITE(7,793)
      DO 790 K=1,NEL
      WRITE(7,791) WHYO(K),AA(K),SLPE(K),ALPHA3(K)
 790  CONTINUE
      WRITE(7,*)
      WRITE(7,*)
      ELSEIF(IF7.EQ.0)THEN
      GOTO 3020
      ELSE
      WRITE(*,794)
      GOTO 3021
      ENDIF
 3020 CONTINUE
C**
C** WRITING THE GROUNDWATER INPUT DATA ON OUTPUT FILE
C**
 3023 WRITE(*,862)
      WRITE(*,*)
      WRITE(*,*) ('READ THE PRINTING FLAG : IF8')
      READ(*,*) IF8
      IF(IF8.EQ.1)THEN
      WRITE(7,863)
      DO 860 N=1,NEL
      WRITE(7,861)  PCO(N),HCO(N),WP(N),FC(N),COEFF(N),RMAXZD(N)
     $ ,DMAX(N)
  860 CONTINUE
      WRITE(7,*)
      WRITE(7,*)
      ELSEIF(IF8.EQ.0)THEN
      GOTO 3022
      ELSE
      WRITE(*,864)
      GOTO 3023
      ENDIF
 3022 CONTINUE
```

```
C*************************************************************
C**        PRINT THE DISCHARGES FOR VERIFICATION
C*************************************************************
      WRITE(7,*) ('DISCHARGE QOUTOT IN M3/S')
      WRITE(7,*)
      DO 38 JL=1,168
      WRITE(7,39) QOUTOT(JL,NEL)
   38 CONTINUE
      DO 2500 L=1,168
      QOUTO(L)=QOUTOT(L,NEL)
2500  CONTINUE
C**
C** PLOT THE DISCHARGE VALUES OBTAINED.
      CALL PLOT(QOUTO)
C**
C** THIS PORTION CALCULATES THE SQUARE OF THE CORRELATION
C** COEFFICIENT R**2 KNOWN AS RSQ IN THE FORTRAN CODE OF
C** THE PROGRAM THE OUTFLOW IS ACCEPTED IF RSQ IS LARGER OR
C** EQUAL TO 0.80 OTHERWISE THE SIMULATION CONTINUES UNTIL
C** THAT CONDITION IS MET.
C**
      ERROR1=0.0
      ERROR2=0.0
      DO 106 JF=1,168
      ERR1(JF)=QREAD(JF,NEL)-QOUTOT(JF,NEL)
      ERROR1=ERROR1+(ERR1(JF))**2
      ERR2(JF)=QREAD(JF,NEL)-QUBAR
      ERROR2=ERROR2+(ERR2(JF)**2)
 106  CONTINUE
      RSQ=1-(ERROR2/ERROR1)
      WRITE(7,*) ('THIS IS THE VALUE OF THE CORRELATION COEF-
     $ FICIENT RSQ')
      WRITE(7,*) RSQ
      IF(RSQ.LT.0.80)THEN
      WRITE(7,*) ('MAKE CHANGES IN INPUT FILES AND RERUN THE
     $ MODEL TO OBTAIN BETTER DISCHARGE VALUES')
      ELSE
      WRITE(7,*) ('THE FLOW VALUES OBTAINED ARE GOOD NO
     $ FURTHER CALIBRATION IS NECESSARY')
      ENDIF
  480 FORMAT(7(1X,F6.2))
  481 FORMAT(7(1X,F6.2))
  482 FORMAT(/,1X,'ENTER 1 IO PRINT DISCHARGE INPUT DATA IN
     $  THE  OUTPUT'/,1X,'FILE  OR  ENTER  0  TO  DISALLOW  THE
PRINTING')
  483 FORMAT(/,1X,'ORIGINAL DISCHARGES DATA USED FOR MODEL
     $ VERIFICATION'/,20X,'UNITS = M3/S'//)
  484 FORMAT(/,1X,'ERROR: WRONG IF1 VALUE')
  561 FORMAT(12(1X,F5.3))
  562 FORMAT(/,1X,'ENTER 1 TO PRINT PRECIPITATION INPUT DATA IN
     $  THE  OUTPUT'/,1X,'FILE  OR  ENTER  0  TO  DISALLOW  THE
PRINTING')
  563    FORMAT(/,1X,'PRECIPITATION  INPUT  DATA;    UNITS  :
M/HR'/,1X,
     $ '168 HOURLY DATA VALUES RECORDED'/)
  564  FORMAT(/,1X,'ERROR: WRONG IF2 VALUE')
  661  FORMAT(4(1X,F6.2))
  662  FORMAT(/,1X,'ENTER 1 TO PRINT TEMPERATURE & EVAPORATION
INPUT
     $ DATA FILE IN THE OUTPUT'/,'OR ENTER 0 TO DISALLOW IT')
  663   FORMAT(/,1X,'WEEKLY TEMPERATURE AND EVAPORATION INPUT
DATA'/,
     $ 1X,' TMIN ',1X,' TMAX ',1X,'CSOLRA',1X,'JULDAY'/
     $ ,10X,'UNITS:'//
     $ ,1X,'  O C  ',1X,'  O C ',1X,'MM/DAY ',1X, '    '/)
  664  FORMAT(/,1X,'ERROR: WRONG IF3 VALUE')
  761  FORMAT(1X,F6.2)
  762  FORMAT(/,1X,'ENTER 1 TO PRINT FIRST INTERCEPTION DATA IN
     $ THE OUTPUT'/,1X,'FILE OR 0 TO DISALLOW THE PRINTING')
  763  FORMAT(/,1X,'FIRST INTERCEPTION INPUT DATA'/,
     $ 1X,'AREA: ALL   '/,
     $ 1X,'UNITS:'//
     $ ,1X,'  KM2  '/)
  764  FORMAT(/,1X,'ERROR: WRONG IF4 VALUE')
  771  FORMAT(1X,F6.1,1X,I9)
  772  FORMAT(/,1X,'ENTER 1 TO PRINT SECOND INTERCEPTION DATA IN
     $ THE OUTPUT'/,1X,'FILE OR 0 TO DISALLOW THE PRINTING')
  773  FORMAT(/,1X,'SECOND INTERCEPTION INPUT DATA'/,
     $ 1X,'  DS ',3X,'   M   '/,
     $ 5X,'UNITS:'//
     $ ,1X,'  CM ',1X,'NUMBER OF TREES/HA'/)
  774  FORMAT(/,1X,'ERROR: WRONG IF5 VALUE')
                                     7              8               1
FORMAT(1X,F6.4,1X,F4.2,1X,F6.4,2X,F4.2,3X,F4.2,1X,F7.4,2X,
     $ F6.4)
  782  FORMAT(/,1X,'ENTER 1 TO PRINT INFILTRATION INPUT DATA IN
     $ THE OUTPUT'/,1X,'FILE OR 0 TO DISALLOW THE PRINTING')
  783   FORMAT(/1X,'INFILTRATION AND DEPRESSION STORAGE INPUT
DATA'/,
     $  1X,'  RATE    ',1X,'WACS',1X,'  SAV  ',2X,'  DL  ',5X,'
WIC',3X,'
     $ HKS   ',2X,'  DE  '/,
     $ 20X,'UNITS:'//
     $ 1X,' %/HR   ',1X,'      ',1X,'   M   ',2X,' M   ',1X,'
',3X,'CM/HR'
     $ 2X,'  M    '/)
  784  FORMAT(/,1X,'ERROR: WRONG IF6 VALUE')
  791  FORMAT(1X,F7.4,1X,F8.2,1X,F8.6,1X,F6.1)
  792  FORMAT(/,1X,'ENTER 1 TO PRINT OVERLAND FLOW INPUT DATA IN
     $ THE OUTPUT'/,1X,'FILE OR 0 TO DISALLOW THE PRINTING')
  793  FORMAT(/,1X,'OVERLAND FLOW INPUT DATA'//,
     $ 1X,'  WHY0  ',1X,'   AA   ',1X,'  SLPE  ',1X,'ALPHA3'//,
     $ 10X,'UNITS:'//,
     $ 1X,'   M    ',1X,'   M    ',1X,'        ',1X,'  DEGREES'/)
  794  FORMAT(/,1X,'ERROR: WRONG IF7 VALUE')
  861  FORMAT(2(1X,F7.4),2(1X,F6.4),1X,F9.3,2(1X,F5.2))
  862  FORMAT(/,1X,'ENTER 1 TO PRINT OVERLAND FLOW INPUT DATA IN

     $ THE OUTPUT'/,1X,'FILE OR 0 TO DISALLOW THE PRINTING')
  863  FORMAT(/,1X,'GROUNDWATER FLOW INPUT DATA'//,
     $ 1X,'  PCO   ',1X,'  HCO   ',1X,'WIC  ',1X,'  FC   ',1X,
     $ ' COEFF ',1X,'RMAXZD',1X,' DMAX '//,
     $ 25X,'UNITS:'//,
     $ 35X,'       M   ',1X,'  M  '/)
 864  FORMAT(/,1X,'ERROR: WRONG IF8 VALUE')
 871  FORMAT(1X,F7.2,1X,F7.2,1X,F4.2,1X,F8.6)
 872  FORMAT(/,1X,'ENTER 1 TO PRINT CHANNEL INPUT DATA IN
     $ THE OUTPUT '/,1X,'FILE OR 0 TO DISALLOW THE PRINTING')
 873  FORMAT(/,1X,'CHANNEL FLOW INPUT DATA'//,
     $ 1X,'  RLEN ',1X,' HTOTC ',1X,' XX ',1X,'   SLOP '//,
     $ 10X,'UNITS: '//,
     $ 1X,'   M   ',1X,'   M    ',1X,'    ','    '/)
 874  FORMAT(/,1X,'ERROR: WRONG IF9 VALUE')
 880  FORMAT(5X,'********************')
 779  FORMAT(5X,'*','THIS IS THE OUTPUT', '*')
 881  FORMAT(5X,'*',7X,'OF',9X,'*')
 882  FORMAT(5X,'*',4X,'TROPICS',7X,'*')
 883  FORMAT(5X,'********************'/)
 884  FORMAT(5X,'BASIN NAME:',1X,A20)
 885  FORMAT(5X,'BASIN AREA:',1X,F10.2,1X,'KM2')
   5  FORMAT(12(1X,F5.3))
  17  FORMAT(2X,I6,2X,F8.5)
  18  FORMAT(4(1X,F6.2))
  23  FORMAT(24X,F6.2)
  39  FORMAT(1X,F8.4)
 240  FORMAT(1X,F7.2,1X,F7.2,1X,F4.2,1X,F8.6)
 270  FORMAT(1X,F4.2,1X,F8.4,1X,F6.3,1X,F8.4,1X,F8.4)
 280  FORMAT(1X,F8.4,3X,F7.2)
 290  FORMAT(1X,F7.3,2X,F7.2)
 150  FORMAT(14X,F7.4,1X,F8.2,1X,F8.6,1X,F6.1)
 120  FORMAT(2(1X,F7.4),2(1X,F6.4),1X,F9.3,2(1X,F5.2))
 242  FORMAT(1X,F6.4,1X,F4.2,1X,F6.4,2X,F4.2,3X,F4.2,1X,F7.4,
     $ 2X,F7.4)
 243  FORMAT(1X,F10.2,1X,F6.2,1X,F8.6,1X,F7.4)
2300  FORMAT(1X,F6.1,1X,I8)
1900  FORMAT(A3)
2000  FORMAT(A3)
2001  FORMAT(A1)
2002  FORMAT(A3)
2003  FORMAT(A3)
2004  FORMAT(A3)
  47  STOP
      END
C***********************************************************************
C** THIS IS THE END OF THE MAIN PROGRAM OF TROPICS.  THE FOL-
C** LOWING IS THE LIST OF THE 22 SUBROUTINES FOUND IN TROPICS
C** THERE ARE INTRODUCED AS THEY ARE CALLED BY THE MAIN PORTION
C** OF THE PROGRAM./.
C***********************************************************************
C**   SUBROUTINE ORDER ; ORDER THE RAW RAINFALL DATA AND
C**   MAKES IT USABLE BY SUBROUTINE REORD.
C***********************************************************************
      SUBROUTINE ORDER(NCT,RAIN,NTIM)
      COMMON /BLOCK1/ NFI(168),NLT(168),RFI(168),RLT(168)
      COMMON /BLOCK6/ KTIM(170),RAW(170)
      INTEGER NTIM(168)
      REAL RAIN(168)
      NCT=0
      DO 100 I=2,169
      IF((RAW(I).NE.0.0).AND.(RAW(I+1).EQ.0.0))THEN
      NCT=NCT+1
      NLT(NCT)=KTIM(I)
      GOTO 104
  104 DO 105 J=I-1,1,-1
      IF(RAW(J).EQ.0.0)THEN
      NFI(NCT)=KTIM(J+1)
      K=J+1
      GOTO 200
      ENDIF
  105 CONTINUE
  200 DO 201 L=NFI(NCT),NLT(NCT)
      RAIN(L)=RAW(L+1)
      NTIM(L)=KTIM(L+1)
  201 CONTINUE
      ENDIF
  100 CONTINUE
      DO 600 JJ=1,NCT
      DO 601 JJJ=NFI(JJ),NLT(JJ)
      WRITE(7,*) NTIM(JJJ),RAIN(JJJ)
  601 CONTINUE
  600 CONTINUE
      RETURN
      END
CB**
C** SUBROUTINE REORD TAKES THE DATA OBTAINED FROM SUBROUTINE
C** ORDER AND DEFINES THE INDEPENDANT EVENTS SPACED BY AT
C** LEAST TL : THE MINIMUM INTEREVENT TIME
C**
      SUBROUTINE REORD(KM,TL,TB,NF2,NL2,NT2,RF2,NTIME,
     $ RAINF,RAINF2,NCT)
      COMMON /BLOCK1/ NFIRST(168),NLAST(168),RFIRST(168),
     $ RLAST(168)
      INTEGER TBN(168),NL2(168),NT2(168),NF2(168),
     $ NTIME(168),TB(168),NCT
      REAL RAINF(168),RAINF2(168),RL2(168),RF2(168)
      DO 460 LL=KM,NCT+1
      IF((TB(LL).LT.TL).AND.(TB(LL+1).GE.TL))THEN
      NL2(LL+1)=NLAST(LL+1)
      RL2(LL+1)=RLAST(LL+1)
      TBN(LL+1)=TB(LL+1)
      M=LL+1
      DO 710 JJ=M-1,KM,-1
      IF(TB(JJ).GE.TL)THEN
      NF2(JJ)=NFIRST(JJ)
      RF2(JJ)=RFIRST(JJ)
      JJJ=JJ
      TBN(JJJ)=TB(JJ)
      GOTO 730
      ENDIF
  710 CONTINUE
  730  DO 740 LLL=NF2(JJJ),NL2(M)
       RAINF2(LLL)=RAINF(LLL)
       NT2(LLL)=NTIME(LLL)
  740  CONTINUE
       ELSEIF((TB(LL).GE.TL).AND.(TB(LL+1).GE.TL))THEN
       NL2(LL)=NLAST(LL)
       RL2(LL)=RLAST(LL)
       NF2(LL)=NFIRST(LL)
       TBN(LL)=TB(LL)
       NL2(LL+1)=NLAST(LL+1)
       NF2(LL+1)=NFIRST(LL+1)
       RL2(LL+1)=RLAST(LL+1)
       DO 750 KPRIME=NF2(LL),NL2(LL)
       RAINF2(KPRIME)=RAINF(KPRIME)
       NT2(KPRIME)=NTIME(KPRIME)
  750  CONTINUE
       DO 751 KPRIM=NF2(LL+1),NL2(LL+1)
       RAINF2(KPRIM)=RAINF(KPRIM)
       NT2(KPRIM)=NTIME(KPRIM)
  751  CONTINUE
       ENDIF
  460  CONTINUE
       RETURN
       END
C**
C**   SUBROUTINE ATEMPE CALCULATES THE HOURLY TEMPERATURES
C**   FROM THE MAXIMUM AND MINIMUM DAILY TEMPERATURE READINGS.
C**   A SINE CURVE IS USED FOR THE CALCULATIONS.
C**
       SUBROUTINE ATEMPE(TEM,NC)
       COMMON /BLOCK5/ TMIN(7),TMAX(7),CSOLRA(7)
       COMMON /BLOCK9/ ATEM(7,24),TBAR(7),DTEM(7)
       REAL TEM(168)
       DO 800 L=1,7
       TBAR(L)=(TMIN(L)+TMAX(L))/2
       DTEM(L)=(TMAX(L)-TMIN(L))/2
  800  CONTINUE
       NC=0
       DO 801 I=1,7
       DO 802 J=1,24
       ATEM(I,J)=TBAR(I)+DTEM(I)*SIN(0.2618*J-1.571)
       NC=NC+1
       TEM(NC)=ATEM(I,J)
  802  CONTINUE
  801  CONTINUE
       DO 803 JJ=1,NC
       WRITE(7,*) TEM(JJ)
  803  CONTINUE
       RETURN
       END
C**
C** THE NEXT SUBROUTINE IS SUBROUTINE EVAPO. EVAPO USES THE
C** THE PRIESTLY TAYLORMETHOD OF ET DETERMINATION TO CALCULATE
C**  THE  EVAPOTRANSPIRATION  VALUES.  THE  HOURLY  TEMPERATURES
OBTAI-
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C** NED FROM SUBROUTINE ATEMPE ARE USED AS INPUTS TO THE MODEL.
C**
      SUBROUTINE EVAPO(E0)
      COMMON /BLOCK5/ TMIN(7),TMAX(7),CSOLRA(7),RJLDAY(7)
      COMMON /BLOCK9/ ATEMP(7,24)
      REAL SOLDA(7),CSOLD(7),SPARAD(7,24),TC(7),SVD(7,24),
     $ CLOUDS(7),SLOPES(7,24),AE(7,24),LWR(7,24),LAT,
     $  ET0(7,24),NRAD(7,24),E0(168),G(7,24),SOLARC,Lh,MW,R,SE
,ST,AS
     $ ,ALPHA,TSN,EVT(168),ETP(7,24),SPAS(7),SOLA(7,24),CLOUD(7)
     $ ,SOLRAD(7)
      LAT=18.0
      R=8.3143
      SOLARC=1360
      Lh=2450
      ST=0.0000000567
      ALPHA=1.21
      TSN=12.0
      PSYCON=0.494
      MW=0.018
      NUMBER=0
      DO 500 DAY=1,7
      SOLDA(DAY)=0.39785*SIN(4.869+0.0172*RJLDAY(DAY)+
     $ 0.03345*SIN(6.224+0.0172*RJLDAY(DAY)))
      CSOLD(DAY)=(1-SOLDA(DAY)**2)**0.5
      SPAS(DAY)=0.0
      DO 501 J=1,24
      SOLA(DAY,J)=SOLDA(DAY)*SIN(LAT*0.01745)+COS(LAT*0.01745)*
     $ COS(0.2618*J-TSN)*CSOLD(DAY)
      IF(SOLA(DAY,J).EQ.0.0)THEN
      SPARAD(DAY,J)=0.0
      ELSE
      SPARAD(DAY,J)=SOLA(DAY,J)*SOLARC
      ENDIF
      SPAS(DAY)=SPAS(DAY)+SPARAD(DAY,J)
  501 CONTINUE
      SOLRAD(DAY)=0.0864*SPAS(DAY)
      IF(SOLRAD(DAY).EQ.0.0)THEN
      TC(DAY)=0.0
      CLOUDS(DAY)=0.0
      ELSE
      TC(DAY)=CSOLRA(DAY)/SOLRAD(DAY)
      CLOUD(DAY)=2.33-3.3*TC(DAY)
      IF(CLOUD(DAY).LT.0.0)THEN
      CLOUDS(DAY)=0.0
      ELSEIF(CLOUD(DAY).GT.1.0)THEN
      CLOUDS(DAY)=1.0
      ELSE
      CLOUDS(DAY)=CLOUD(DAY)
      ENDIF
      ENDIF
      DO 502 K=1,24
      SVD(DAY,K)=(EXP(31.3716-6014.79/(ATEMP(DAY,K)+273)-
     $ 0.00792495*(ATEMP(DAY,K)+273)))/(ATEMP(DAY,K)+273)
```

```
SLOPES(DAY,K)=SVD(DAY,K)*((Lh*MW)/R)/((ATEMP(DAY,K)+273)-1)/
     $ (ATEMP(DAY,K)+273)
      AE(DAY,K)=(1-0.84*CLOUDS(DAY))*(0.72+0.005*ATEMP(DAY,K))
     $ +0.84*CLOUDS(DAY)
      LWR(DAY,K)=(AE(DAY,K)-SE)*ST*((ATEMP(DAY,K)+273)**4)
      IF(SPAS(DAY).EQ.0.0)THEN
      NRAD(DAY,K)=LWR(DAY,K)
      ELSE

NRAD(DAY,K)=LWR(DAY,K)+AS*CSOLRA(DAY)*11.574*SPARAD(DAY,K)
     $ /SPAS(DAY)
      ENDIF
      G(DAY,K)=0.1*NRAD(DAY,K)
      ETP(DAY,K)=(ALPHA*(NRAD(DAY,K)-G(DAY,K))*(SLOPES(DAY,K)/(
     $ SLOPES(DAY,K)+PSYCON))/(1000*Lh))*3.6
      NUMBER=NUMBER+1
      EVT(NUMBER)=ETP(DAY,K)

IF((CSOLRA(DAY)*(SPARAD(DAY,K)/(SPAS(DAY)+1)).EQ.0.0).OR.(
     $ ETP(DAY,K).EQ.0.0))THEN
      ET0(DAY,K)=0.0
      E0(NUMBER)=0.0
      ELSE
      ET0(DAY,K)=ETP(DAY,K)
      E0(NUMBER)=EVT(NUMBER)
      ENDIF
  502 CONTINUE
  500 CONTINUE
      DO 503 KJ=1,168
      WRITE(7,*) E0(KJ)
  503 CONTINUE
      RETURN
      END
C**
C** THIS IS SUBROUTINE CHAN WHICH READS THE ADJACENT CHAN
C** NEL SEGMENTS ADJACENT TO A GIVEN CHANNEL SEGMENT
C**
      SUBROUTINE CHAN(LL2,LL1,LL3,LL4,LL5)
      COMMON /BLOCK14/ NSC(55,2)
      INTEGER LL1,LL2,LL3,LL4,LL5
      WRITE(*,*) ('READ THE NUMBER OF CHANNELS ADJACENT TO
     $ THE PRESENT CHANNEL SEGMENT')
      READ(*,*) LL2
      IF(LL2.EQ.1)THEN
      WRITE(*,*) ('READ THE ADJACENT CHANNEL NUMBER')
      READ(*,*) LL3
      LL4=0
      LL5=0
      ELSEIF(LL2.EQ.2)THEN
      WRITE(*,*) ('THERE ARE 2 ADJACENT CHANNEL SEGMENTS')
      WRITE(*,*) ('READ ADJACENT #1 & ADJACENT #2')
      DO 720 K=1,2
      READ(*,*) NSC(LL1,K)
  720 CONTINUE
      LL3=0
      LL4=NSC(LL1,1)
      LL5=NSC(LL1,2)
      ENDIF
      RETURN
      END
C**
C** NOW CALCULATE THE FUNCTION SUBPROGRAM DCOMP TO CALCULATE
C** THE VEGETATION DENSITY DC
C**
      FUNCTION DCOMP(AB,BA,C,NL,PPP,KKA)
      REAL PPP(NL),AB,BA,C,KAPPA
      INTEGER KKA(NL),NL
      SUM=0.0
      KAPPA=(AB**2)*3.14/(4000000.0*C)
      DO 96 KN=1,NL
      SUM=SUM+KKA(KN)*(PPP(KN)**(2*BA))
   96 CONTINUE
      DCOMT=SUM*KAPPA
      IF(DCOMT.GE.1.0)THEN
      DCOMP=1.00
      ELSE
      DCOMP=DCOMT
      ENDIF
      RETURN
      END
C**
C** THE NEXT SUBROUTINES CALCULATE THE COMPONENT PROCESSES
C** i.e, INFILTRATION,INTERCEPTION,AND DEPRESSION STORAGE.
C**
C**** SUBROUTINE INTERP IS THE INTERCEPTION SUBROUTINE. IT
C** CALCULATES THE INTERCEPTION VALUES FOR EACH ELEMENT THROUGH
C** THE ENTIRE SIMULATION TIME.
C**
      SUBROUTINE INTERP(II,NNEWC,SSMAX,DDFC,THRG)
      COMMON /BLOCK7/ NNF3(168),NNL3(168),RRL3(168),RRF3(168)
      COMMON /BLOCK8/ DDT
      INTEGER NNEWC,II
      REAL THRG(55,168),SINTER(55,168),DSIN(55,168),SSMAX
      DO 605 J=1,NNEWC
      SINTER(II,NNF3(J)-1)=0.0
      DO 608 JJ=NNF3(J),NNL3(J)
      DSIN(II,JJ)=RRF3(JJ)*DDFC*DDT
      SINTER(II,JJ)=SINTER(II,JJ-1)+DSIN(II,JJ)
      THRG(II,JJ)=SINTER(II,JJ)-SSMAX+RRF3(JJ)*(1-DDFC)*
     $ DDT
      IF(THRG(II,JJ).LE.0.0)THRG(II,JJ)=0.0
  608 CONTINUE
  605 CONTINUE
      DO 602 KK=1,NNEWC
      DO 603 NNK=NNF3(KK),NNL3(KK)
      WRITE(7,*) NNK,THRG(II,NNK)
  603 CONTINUE
  602 CONTINUE
      RETURN
      END
```

```
C**
C****   INFILTRATION  IS HANDLED BY SUBROUTINE INFILT. INFILT
C**  USES THE GREEN-AMPT EQUATION DERIVED FROM THE RICHARDS
C**  EQUATION TO CALCULATE THE INFILTRATION VALUES FOR EACH
C**  ELEMENT THROUGHOUT THE 168 HOURS OF TOTAL SIMULATION
C**  TIME.
C**
      SUBROUTINE INFILT(I3,NEWCI,NT3,TNEW,TG,FILA,EXCE)
      COMMON/BLOCK2/RATE(55),WACS(55),SAV(55),DL(55),WIC(55),
     $ HKS(55)
      COMMON /BLOCK7/ N3F3(168),N3L3(168),R3L3(168),R3F3(168)
      INTEGER NT3(168),TNEW(168)
      COMMON /BLOCK8/ D3T
      REAL TG(I3,168),EXCE(I3,168),DEFC(169),FILA(I3,168),
     $ WACEND(168),WACI(168)
      D3T=1
      WACI(1)=WIC(I3)
      WACEND(1)=WACS(I3)
      WACI(NEWCI+1)=WACI(NEWCI)
      DEFC(NEWCI+1)=DEFC(NEWCI)
      DEFC(1)=WACEND(1)-WACI(1)
      DO 900 J=1,NEWCI
      DO 901 NJ=N3F3(J),N3L3(J)
      IF(TG(I3,NJ).LE.HKS(I3))THEN
      FILA(I3,NJ)=TG(I3,NJ)
      F=F+FILA(I3,NJ)*D3T
      EXCE(I3,NJ)=0.0
      ELSEIF(TG(I3,NJ).GT.HKS(I3))THEN
      FS=(SAV(I3)*DEFC(J))/((TG(I3,NJ)/HKS(I3))-1)
      FSUM=0.0
      K=NJ
      DO 902 JJ=1,K-1
      FSUM=FSUM+TG(I3,JJ)*D3T
  902 CONTINUE
      FP=FS
      TP=((FP-FSUM)/TG(I3,K))+K-1
      TPRIME=FP/HKS(I3)-SAV(I3)*DEFC(J)*ALOG(1+FP/(DEFC(J)*SAV
     $ (I3)))
      JN=NJ
      GOTO 903
      ENDIF
  901 CONTINUE
C***    CALCULATE INFILTRATION RATE AFTER PONDING
  903 DO 904 KL=JN,N3L3(J)
                                                C     A     L     L
COMPUF(J,KL,I3,SAV(I3),DEFC(J),HKS(I3),TP,TPRIME,FF,FP
     $ ,NT3(KL))
      IF(FF.EQ.0.0)THEN
      FILA(I3,KL)=HKS(I3)*(1+(DEFC(J)*SAV(I3)/(FF+1)))
      ELSE
      FILA(I3,KL)=HKS(I3)*(1+(DEFC(J)*SAV(I3)/FF))
      ENDIF
      EXCE(I3,KL)=TG(I3,KL)-FILA(I3,KL)
      IF(EXCE(I3,KL).LE.0.0)EXCE(I3,KL)=0.0
  904 CONTINUE
```

```
       LL=J
C***  NOW CALCULATE THE NEW MOISTURE CONDITION OF THE SOIL
C**   BEFORE CALCULATING THE NEXT TIME STEP INFILTRATION
C**   VALUE.
       CALL RESET(I3,LL,WACEND(LL),WACS(I3),TNEW(LL),RATE(I3),
     $ DL(I3),FF,WACI(LL+1),DEFC(LL+1))
  900  CONTINUE
       DO 905 JP=1,NEWCI
       DO 906 JJJ=N3F3(JP),N3L3(JP)
       WRITE(7,*) NT3(JJJ),EXCE(I3,JJJ),FILA(I3,JJJ)
  906  CONTINUE
  905  CONTINUE
       RETURN
       END
C**
C**  SUBROUTINE COMPUF OF SUBROUTINE INFILT CALCULATE THE
C**  THE GREEN-AMPT EQUATION USING THE NEWTON-RAPHSON
C**  METHOD
C**
       SUBROUTINE COMPUF(J,JM,I3,SAVV,DEF,HKK,TP,TPRIM,FF,
     $ FP,NT33)
       REAL PHI,DPHI,ALPH(168),CK(168),X,B,CC,FD(1000)
       PHI(X,B,CC)=X-B*ALOG(5.0+X/B)-CC
       DPHI(X,B)=1.0-B/(B+X+1.0)
       ALPH(J)=DEF*SAVV
       CK(JM)=FLOAT(NT33)-TP+TPRIM
       FD(1)=FP
       ERROR=0.001
       DO 1020 N=1,1000
       IF((1.0+(FD(N)/(ALPH(J)+1.0))).LE.0.0)THEN
       ZEKE=PHI(FD(N),(ALPH(J)+1),CK(JM))
       ZEKE=0.0
       ENDIF
       IF(DPHI(FD(N),CK(JM)).EQ.0.0)THEN

FD(N+1)=FD(N)-(PHI(FD(N),(ALPH(J)+1.0),CK(JM))/(DPHI(FD(N),
     $ CK(JM))+1))
       ELSE
       FD(N+1)=FD(N)-(PHI(FD(N),(ALPH(J)+1.0),CK(JM))/DPHI(FD
     $ (N),CK(JM)))
       ENDIF
       DDF=FD(N+1)-FD(N)
       DDDF=ABS(DDF)
       IF(DDDF.GT.ERROR)THEN
       GOTO 1020
       ELSEIF(DDDF.LE.ERROR)THEN
       M=N+1
       GOTO 1025
       ENDIF
 1020  CONTINUE
 1025  CONTINUE
       FFF=FD(M)
       RETURN
       END
C**
```

```
C***  SUBROUTINE RESET CALCULATE THE SOIL MOISTURE CON-
C**   CONDITION FOR NEXT RUN
C**
                               S   U   B   R   O   U   T   I   N   E
RESET(II1,LL,WACE,SWAC,NEW,RRATE,DDD,FFF,WAC,DEFCN)
       INTEGER NEW
       IF(DDD.EQ.0.0)THEN
       WACE=FFF/(DDD+1)
       ELSE
       WACE=FFF/DDD
       ENDIF
       WAC=WACE-RRATE*NEW
       DEFCN=SWAC-WAC
       RETURN
       END
C**
C***  SUBROUTINE DEPST CALCULATES THE DEPRESSION STORAGE
C**
       SUBROUTINE DEPST(I,EXCESS,NNEW,DDE,PRUN)
       REAL VD(168),EXCESS(I,168),PRUN(I,168)
       COMMON /BLOCK7/ NFF3(168),NNL3(168),RRL3(168),RRF3(168)
       COMMON /BLOCK8/ DDT
       VTOTAL=0.0
       DO 450 J=1,NNEW
       DO 451 JI=NFF3(J),NNL3(J)
       VD(JI)=A*(DDE**B)*(1-EXP(-1/A*(1/DDE**B)))*EXCESS(I,JI)
       VTOTAL=VTOTAL+VD(JI)*DDT
       IF(VTOTAL.LT.(A*(DDE**B)))THEN
       PRUN(I,JI)=0.0
       ELSE
       PRUN(I,JI)=EXCESS(I,JI)-VTOTAL
       IF(PRUN(I,JI).LT.0.0)PRUN(I,JI)=0.0
       ENDIF
  451  CONTINUE
  450  CONTINUE
       RETURN
       END
C**
C*** SUBROUTINE CHANIP FITS THE DISHARGE DATA AND THE SURFACE
C*** DATA INTO A REGRESSION CURVE AND CALCULATES THE LEAST
C*** SQUARE COEFFICIENTS GAMMA AND LAMBDA. THE PROGRAM ALSO
C*** COMPUTES THE CHANNEL VELOCITY VM,THE DEPTH YY0,THE WATER
C***  LEVEL  HWC,THE  DISCHARGE  QQ0  AND  THE  CHANNEL  BOTTOM
ELEVATION
C*** HC
       SUBROUTINE CHANIP(NREG,HTOTC,HC,VM,QQ0,YY0,HWC)
       PARAMETER(NMAX=100)
       COMMON /BLOCK10/ XT(100),YT(100),ARR(100),A1,ABDEVT
                   C  O  M  M  O  N     /  B  L  O  C  K  1  1  /
NTOTC,CONCEN(32),QQR(20),SURF(20),ARE1(32)
       COMMON /BLOC16/ X(32),Y(32)
       REAL YY0(55),QQ0(55),VM(55),HC(55),HWC(55),HTOTC(55),
     $ ZF(55),ARE(55),LAMBDA,A,B
       WRITE(7,*) ('DATA FOR REGRESSION ANALYSIS')
       WRITE(7,*)
```

```
      WRITE(7,*)    ('THE    NUMBER    OF    REGRESSION    DATA
POINTS=?'),NREG
      WRITE(7,*)
      WRITE(7,*) ('QQR = DISCHARGES(M/S) SURF= AREAS(KM2)')
      WRITE(7,*) ('   QQR          SURF')
      WRITE(7,*)
      DO 1111 LK=1,NREG
      WRITE(7,*) QQR(LK),SURF(LK)
 1111 CONTINUE
      DO 115 L=1,NREG
      X(L)=ALOG(SURF(L))
      Y(L)=ALOG(QQR(L))
  115 CONTINUE
      CALL MEDFIT(A,B,NREG,ABDEV)
      GAMMA=EXP(A)
      LAMBDA=B
      WRITE(7,112)
      WRITE(7,117) GAMMA,LAMBDA
      DO 119 LL=1,NTOTC
      IF(LAMBDA.EQ.0.0)THEN
      QQ0(LL)=GAMMA
      ELSE
      QQ0(LL)=GAMMA*((ARE1(LL))**LAMBDA)
      ENDIF
  119 CONTINUE
      DO 220 K=1,NTOTC
      YY0(K)=2.11*((QQ0(K)/CONCEN(K))**0.333)
      VM(K)=0.0983*(QQ0(K)**0.167)/(CONCEN(K)**0.333)
      ZF(K)=1/3.28+0.25*YY0(K)
      HWC(K)=HTOTC(K)-ZF(K)
      HC(K)=HWC(K)-YY0(K)
      IF(HC(K).LT.0.0)THEN
      HC(K)=0.0
      ENDIF
 220  CONTINUE
      WRITE(7,*)
      WRITE(7,54)
      WRITE(7,*)
      WRITE(7,57)
      WRITE(7,*)
      DO 55 I=1,NTOTC
      WRITE(7,56) YY0(I),VM(I),HWC(I),HC(I)
  55  CONTINUE
      WRITE(7,*)
      WRITE(7,*)
 112  FORMAT(5X,'GAMMA',5X,'LAMBDA')
 117  FORMAT(2X,F10.8,2X,F10.8)
  54  FORMAT(7X,'YY0',10X,'VM',6X,'WLVEL',6X,'CBOTTOM')
  57  FORMAT(7X,' M ',10X,'M ',6X,'  M  ',6X,'   M   ')
  56  FORMAT(4(2X,F10.4))
      RETURN
      END
C**
C*** SUBROUTINE MEDFIT IS THE SUBROUTINE WHICH PERFORMS THE
C**  REGRESSION FITTING WITHIN SUBROUTINE CHANIP
```

```
C**
      SUBROUTINE MEDFIT(A,B,NREG,ABDEV)
      PARAMETER(NMAX=100)
      EXTERNAL ROFUNC
      COMMON /BLOCK10/ XT(100),YT(100),ARR(100),A1,ABDEVT
      COMMON /BLOCK16/ X(32),Y(32)
      SX=0.0
      SY=0.0
      SXY=0.0
      SXX=0.0
      DO 310 J=1,NREG
      XT(J)=X(J)
      YT(J)=Y(J)
      SX=SX+X(J)
      SY=SY+Y(J)
      SXY=SXY+X(J)*Y(J)
      SXX=SXX+X(J)**2
  310 CONTINUE
      DEL=NREG*SXX-SX**2
      IF(DEL.EQ.0.0)THEN
      A1=(SXX*SY-SX*SXY)/(DEL+1)
      BB=(NREG*SXY-SX*SY)/(1+DEL)
      ELSE
      A1=(SXX*SY-SX*SXY)/DEL
      BB=(NREG*SXY-SX*SY)/DEL
      ENDIF
      CHISQ=0.0
      DO 330 K=1,NREG
      CHISQ=CHISQ+(Y(K)-(A1+BB*X(K)))**2
  330 CONTINUE
      IF(DEL.NE.0.0)THEN
      SIGB=SQRT(CHISQ/DEL)
      ELSE
      SIGB=SQRT(CHISQ/(DEL+1))
      ENDIF
      B1=BB
      F1=ROFUNC(B1,NREG)
      B2=BB+SIGN(3.0*SIGB,F1)
      F2=ROFUNC(B2,NREG)
  311 IF(F1*F2.GT.0.0)THEN
      BB=2.0*B2-B1
      B1=B2
      F1=F2
      B2=BB
      F2=ROFUNC(B2,NREG)
      GOTO 311
      ENDIF
      SIGB=0.01*SIGB
  312 IF(ABS(B2-B1).GT.SIGB)THEN
      BB=0.5*(B1+B2)
      IF((BB.EQ.B1).OR.(BB.EQ.B2))GOTO 333
      F=ROFUNC(BB,NREG)
      IF(F*F1.GE.0.0)THEN
      F1=F
      B1=BB
      ELSE
      F2=F
      B2=BB
      ENDIF
      GOTO 312
      ENDIF
  333 A=A1
      B=BB
      ABDEV=ABDEVT/NREG
      RETURN
      END
C**
C*** FUNCTION ROFUNC GIVE THE BEST REGRESSION VALUES
C*** GAMMA AND BETHA
C**
      FUNCTION ROFUNC(B,NREG)
      PARAMETER(NMAX=100)
      COMMON /BLOCK10/ XT(100),YT(100),ARR(100),A1,ABDEVT
      COMMON /BLOCK16/ X(32),Y(32)
      N1=NREG+1
      NML=N1/2
      NMH=N1-NML
      DO 400  J=1,NREG
      ARR(J)=Y(J)-B*X(J)
  400 CONTINUE
      CALL SORT(NREG,ARR)
      A1=0.5*(ARR(NML)+ARR(NMH))
      SUM=0.0
      ABDEV=0.0
      DO 405 J=1,NREG
      D=Y(J)-(B*X(J)+A1)
      ABDEV=ABDEV+ABS(D)
      SUM=SUM+X(J)*SIGN(1.0,D)
  405 CONTINUE
      ROFUNC=SUM
      RETURN
      END
C**
C** SUBROUTINE SORT; SORTS THE DATA
C**
      SUBROUTINE SORT(NREG,ARR)
      REAL ARR(NREG)
      L=NREG/2+1
      IR=NREG
 410  CONTINUE
      IF(L.GT.1)THEN
      L=L-1
      RRA=ARR(L)
      ELSE
      RRA=ARR(IR)
      ARR(IR)=ARR(1)
      IR=IR-1
      IF(IR.EQ.1)THEN
      ARR(1)=RRA
      RETURN
      ENDIF
      ENDIF
      I=L
      J=L+L
  420 IF(J.LE.IR)THEN
      IF(J.LT.IR)THEN
      IF(ARR(J).LT.ARR(J+1))J=J+1
      ENDIF
      IF(RRA.LT.ARR(J))THEN
      ARR(I)=ARR(J)
      I=J
      J=J+J
      ELSE
      J=IR+1
      ENDIF
      GOTO 420
      ENDIF
      ARR(I)=RRA
      GOTO 410
      END
C**
C** THE FOLLOWING SUBROUTINE ESTIMATE FLOW PROCESSES.
C** THE FIRST OF THESE ROUTINES IS THE OVERLAND FLOW ROUTINE
C** OVLAND WHICH HAS TWO SUBROUTINES ITSELF: ADJACE AND COMPY.
C**
      SUBROUTINE OVLAND(IM,KM,QQI,NNUM,PARM,SSC,AAA,WW2,ARE,
     $ PRUNA,EK,ALP,YK1,WHYY0,CLAS,QII,QBB,LEV,SL,YK2,QOV)
      CHARACTER*1 SSC(55,6)
      COMMON/BLOCK12/Q1H(168,55),Q2H(168,55),Q1V(168,55),Q2V(
     $ 168,55)
      COMMON /BLOCK13/ INCA(55,6)
      DIMENSION WW2(55,6),AAA(55)
      REAL EK,PARAM
      IF(LEV.NE.1)THEN
      CALL ADJACE(IM,KM,QQI,NNUM,SSC,AAA,WW2,QII,QBB)
C**
C**  NOW SOLVE THE OVERLAND FLOW EQUATION TO FIND YK AND
C**  QOVK: THE WATER DEPTH AND THE OVERLAND FLOW DISCHARGE
C**  SUBROUTINE COMPUY DOES THE CALCULATIONS USING THE NEWTON
C**  RAPHSON METHOD
C**
      CALL  COMPUY(IM,KM,ALP,ARE,QBB,PRUNA,PARM,YK1,WHYY0,SL,EK,
     $ ,YK2,QOV)
      IF((CLAS.EQ.2).OR.(CLAS.EQ.4))THEN
      IF(COS(ALP).LE.0.0)THEN
      Q1H(KM+1,IM)=-QOV*COS(0.01745*ALP)
      Q1V(KM+1,IM)=QOV*SQRT(1-COS(0.01745*ALP)**2)
      ELSE
      Q1H(KM+1,IM)=QOV*COS(0.01745*ALP)
      Q1V(KM+1,IM)=QOV*SQRT(1-COS(0.01745*ALP)**2)
      ENDIF
      ENDIF
      ELSE
C** CALCULATING QOV FOR FIRST LEVEL ELEMENTS
      CALL  COMPUY(IM,KM,ALP,ARE,0.0,PRUNA,PARM,YK1,WHYY0,SL,EK,
     $ ,YK2,QOV)
      ENDIF
      RETURN
      END
C**   SUBROUTINE ADJACE ESTIMATION
      SUBROUTINE ADJACE(IN,IK,QQ1,NUM,SSCC,AAA,WWW,QQI2,QBAR2)
                  COMMON /BLOCK12/
QQH(168,55),QQHH(168,55),QQV(168,55),QQVV(
     $ 168,55)
      COMMON /BLOCK13/ IIN(55,6)
      CHARACTER*1 SSCC(55,6)
      REAL WWW(55,6),AAA(55)
      DO 700 K=1,NUM
      IF(SSCC(IN,K).EQ.'H')THEN
      QQHH(IK,IIN(IN,K))=(WWW(IN,K)/(AAA(IIN(IN,K))+1.0))*
     $ QQH(IK,IIN(IN,K))
      ELSEIF(SSCC(IN,K).EQ.'V')THEN
      QQVV(IK,IIN(IN,K))=(WWW(IN,K)/(AAA(IIN(IN,K))+1.0))*
     $ QQV(IK,IIN(IN,K))
      ENDIF
 700  CONTINUE
      DO 701 KP=1,NUM
      QQI2=QQVV(IK,IIN(IN,KP))+QQHH(IK,IIN(IN,KP))
 701  CONTINUE
      QBAR2=(QQI2+QQI1)/2
      RETURN
      END
C** NOW PERFORM THE CALCULATION OF Y(K,I) AND QOVA(K,I)
C** WITH SUBROUTINE COMPY
      SUBROUTINE COMPUY(KK,II,ALP,ARA,QB,PF,PAM,YYY1,YYY0,
     $ SSL,EK,YYY2,QOVA2)
      COMMON /BLOCK8/ DDDT
      EXTERNAL HANDLE
      REAL FUNC(800),ZZ(800)
      FUNCT(QY,SP,AAL,PFF,YY2,EK,PAR,YY1,D1DT)=
     $ QY+277.78*AAL*PFF-
     $ (0.5*(SQRT(19620000.0*SP*AAL)))*(SQRT(1.0/(0.32/
     $ (1.0+(ALOG((10.94/EK)*
                                                                  $
YY2+3.2))**2)+PAR*YY2))+SQRT(1.0/(0.32/(1.0+(ALOG((10.94/EK)*
                                                                  $
YY1+3.2))**2)+PAR*YY1)))-(1000000.0*AAL/(3600.0*DDT+1.0))*
     $ (YY2-YY1)
       DFUNCT(SP,AAL,YY2,EK,PAR)=0.25*SQRT
     $ (19620000.0*SP*AAL)*
                                                                  $
(1.0/((0.32/((ALOG((10.94/EK)*YY2+3.2))**2+1.0)+PAR*YY2)**1.5))*
                                                                  $
(PAR-7.0/(1.0+(10.94*YY2+EK+1.0)*((ALOG((10.94/EK)*YY2+3.2))**
3))
     $ )
      CALL LIB$ESTABLISH (HANDLE)
      EROR=0.5
      FUNC(1)=YYY1
      DO 1100 N=1,799
      ZZ(N)=DFUNCT(SSL,ARA,FUNC(N),EK,PAM)
      FUNC(N+1)=FUNC(N)-(FUNCT(QB,SSL,ARA,PF,FUNC(N),EK,PAM
     $ ,YYY1,DDDT)/(ZZ(N)+1))
      DDFUN=FUNC(N+1)-FUNC(N)
      DDDFUN=ABS(DDFUN)
      IF(DDDFUN.GT.EROR)THEN
      GOTO 1100
      ELSEIF(DDDFUN.LE.EROR)THEN
      M=N+1
      GOTO 1101
      ENDIF
 1100 CONTINUE
      YYY2=FUNC(800)
      YF=0.32/(1.0+(ALOG((10.94/EK)*YYY2+1.2))**2)+PAM*YYY2
      QOVA2=SQRT(19620000.0*SSL*ARA/(YF+1.0))
      GOTO 1102
 1101 CONTINUE
 1102 RETURN
      END
      INTEGER*4 FUNCTION HANDLE(SIGARGS,MECHARGS)
      INTEGER*4 SIGARGS(*),MECHARGS(5)
      INCLUDE 'SYS$LIBRARY:SIGDEF'
      INCLUDE 'SYS$LIBRARY:MTHDEF'
      IF(SIGARGS(2).EQ.MTH$_FLOOVEMAT)THEN
      MECHARGS(4)='FFFF7FFF'X
      MECHARGS(5)='FFFFFFFF'X
      HANDLE=SS$_CONTINUE
      ELSE
      HANDLE=SS$RESIGNAL
      ENDIF
      RETURN
      END
C**
C*** THIS IS SUBROUTINE GWATER WHICH CALCULATES THE GROUND-
C**  WATER RELEASE GWR.
C**
      SUBROUTINE GWATER(I,K,EOK,JJI,WAC,HTO,FI,PO,HK1,WACII,
     $ THET1,FFC,WWP,HKKS,HOC,POC,RMAX,DMX,COF,THET2,HK2,GWRA)
      COMMON /BLOCK8/ DT
      REAL WAC,EOC,GW,THET2,THET1,PERC,DEN,KA,HTEMP,DHH
      INTEGER JJI,K,I
      KA=1.0
C**  NOW CALCULATE THT2 WITH SUBROUTINE COMPTH
      HTEMP=HK1
      DHH=HTO-HK1
      IF(ABS(DHH).LE.0.1)THEN
      HK1=HTEMP+1.0
      ELSE
      HK1=HTEMP
      ENDIF
      CALL COMPTH(I,K,HK1,THET1,FI,PO,HOC,FFC,HKKS,POC
     $ ,EOK,WWP,SLO,HTO,WACII,THET2)
      PERCO=WAC*EXP((THET2-PO)*HOC)*(1.0+2.0*POC*(THET2-FFC))/
     $ (HTO-HK1)
      DEN1=PO+THET1-2*THET2
```

```
       IF(DEN1.EQ.0.0)THEN
       DEN=DEN1+1.0
       ELSE
       DEN=DEN1
       ENDIF
       DAN1=DEN*RMAX
       IF(DAN1.EQ.0.0)THEN
       DAN=DAN1+1.0
       ELSE
       DAN=DAN1
       ENDIF
       DAN3=DEN*DMX
       IF(DAN3.EQ.0.0)THEN
       DAN2=DAN3+1.0
       ELSE
       DAN2=DAN3
       ENDIF
       HK2=((PERCO/DEN)*DT-(RMAX-HTO+HK1/2.0)*EOK*DT*KA)/
     $ DAN-(DMX-HTO+HK1/2.0)*COF*DT*3600.0/(DAN
     $ +HK1)/(1.0+((EOK*DT*KA)/(2.0*DAN)))+
     $ (3600.0*DT*COF/(2.0*DAN2))
       GWRA=COF*(DMX-(HTO-(HK1+HK2)/2.0))/(0.5+DMX)
       RETURN
       END
C**    NOW USE SUBROUTINE COMPTH
       SUBROUTINE COMPTH(I,K,HK1,THET1,FI,PO,HOC,FFC,HKKS,
     $ POC,EOK,WWP,SLO,HTO,WACII,THET2)
       EXTERNAL HDLR
       COMMON /BLOCK8/ DT
                                            R     E     A     L
THFUN(100),WACII,THZUN(100),THZUN1(100),TEMPO,TMP(100)
       FUN(HH1,THH1,HHTOT,FFIL,THH2,HKSAT,POR2,HHCO,PPCO,
     $ FFFC,DDT,WW1P,EE0)=(1.0/(HHTOT-HH1))*((FFIL-EE0)*
     $ DDT-(((THH2-FFFC)/(FFFC-WW1P+0.17945))*EE0*DDT))
     $ -(1.0/(HHTOT-HH1))*HKSAT*EXP((THH2-POR2)*HHCO)*(1.0+2.0*
     $ PPCO*((THH2-FFFC)/(HHTOT-HH1)))*DDT+THH1-THH2
       DFUN(HH1,THH1,HHTOT,THH2,HKSAT,POR2,HHCO,PPCO,
     $  FFFC,DDT,WW1P,EE0)=(-1.0/(HHTOT-HH1))*(EE0*DDT/(FFFC-WW1P
                                                              $
+0.17945))-(1.0/(HHTOT-HH1))*(HKSAT*EXP((THH2-POR2)*HHCO)*
     $ (HHCO*(1.0+2.0*PPCO*((THH2-FFFC)/(HHTOT-HH1)))+2.0*PPCO*
     $ (1.0/(HHTOT-HH1))))*DDT-1.0
       CALL LIB$ESTABLISH (HDLR)
       ERR=0.005
       THFUN(1)=WACII
       DO 1400 ITER=1,99
       THZUN1(ITER)=DFUN(HK1,THET1,HTO,THFUN(ITER),HKKS,PO,HOC
     $ ,POC,FFC,DT,WWP,EOK)
       IF(THZUN1(ITER).LE.-1.0E+15)THEN
       THZUN(ITER)=-1.0E+15
       ELSE
       THZUN(ITER)=THZUN1(ITER)
       ENDIF
       THFUN(ITER+1)=THFUN(ITER)-FUN(HK1,THET1,HTO,FI,THFUN(
     $ ITER),HKKS,PO,HOC,POC,FFC,DT,WWP,EOK)/(THZUN(ITER)+0.99)
```

```
      DFN=THFUN(ITER+1)-THFUN(ITER)
      DDFN=ABS(DFN)
      IF(DDFN.GT.ERR)THEN
      TMP(ITER+1)=THFUN(ITER+1)
      IF(TMP(ITER+1).LE.0.0)THEN
      THFUN(ITER+1)=FFC
      ELSEIF(TMP(ITER+1).GT.PO)THEN
      THFUN(ITER+1)=PO
      ELSE
      THFUN(ITER+1)=TMP(ITER+1)
      ENDIF
      IF((ITER+1).EQ.100)THEN
      GOTO 1601
      ELSE
      GOTO 1400
      ENDIF
      ELSE
      GOTO 1401
      ENDIF
 1400 CONTINUE
 1401 CONTINUE
 1601 CONTINUE
      TEMPO=THFUN(ITER+1)
      IF(TEMPO.LE.0.0)THEN
      THET2=FFC
      ELSEIF(TEMPO.GT.PO)THEN
      THET2=PO
      ELSE
      THET2=TEMPO
      ENDIF
      RETURN
      END
      INTEGER*4 FUNCTION HDLR(SIGARGS,MECHARGS)
      INTEGER*4 SIGARGS(*),MECHARGS(5)
      INCLUDE 'SYS$LIBRARY:SIGDEF'
      INCLUDE 'SYS$LIBRARY:MTHDEF'
      IF(SIGARGS(2).EQ.MTH$_FLOOVEMAT)THEN
      MECHARGS(4)='FFFF7FFF'X
      MECHARGS(5)='FFFFFFFF'X
      HDLR=SS$_CONTINUE
      ELSE
      HDLR=SS$_RESIGNAL
      ENDIF
      RETURN
      END
C**
C**  THIS IS SUBROUTINE MUSKIN : MUSKIN CALCULATES CHANNEL FLOW
C**  USING THE MUSKINGUM ROUTING METHOD.
C**
                        SUBROUTINE
MUSKIN(CC0,CC1,CC2,QI1,QI,QOVAL,QGW,QC01,QC02,QOU)
      QC02=CC0*QI+CC1*QI1+CC2*QC01
      QOU=QC02+QOVAL+QGW
      RETURN
      END
```

```
C**A
C**   THIS IS SUBROUTINE ADD : ADD ADDS THE FLOWS OF CHANNEL
C**   SEGMENTS DRAINING TO THE LAKE FOR EACH SIMULATION TIME
C**   STEP
C**
      SUBROUTINE ADD(QSM1,QTLC,SUM,QSM2)
      QSUM2=ASM1+QTLC+SUM
      RETURN
      END
C**
C**** THIS IS SUBROUTINE LROUTE USED TO PERFORM LAKE FLOW
C**   ROUTING.
C**
      SUBROUTINE LROUTE(Q11,Q22,HL1,APL,AL,SL,NR,RFF1,RFF2,
     $ EK01,EK02,HL2,QO2)
      COMMON /BLOCK8/ DT
      REAL IBAR,NR,FUNF(100)
      FFUN(Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9,Z10)=(Z10-Z3)/Z9
     $ -(Z1+Z2)/2+Z4/Z5*(1/Z7)*(((Z3+Z10)/2)**(5/3))*(Z6**0.5)
      DFFUN(Z3,Z4,Z5,Z6,Z7,Z9,Z10)=1/Z9+(5/6)*(1/Z7)*(Z4/Z5)
     $ *(((Z3+Z10)/2)**(2/3))*(Z6**0.5)
      IBAR=(RF1+RF2)/2-(EK01+EK02)/2
      IF(IBAR.LE.0.0)IBAR=0.0
      ERR5=0.001
      FUNF(1)=HL0
      DO 1500 L=1,100
      FUNF(L+1)=FUNF(L)-(FFUN(Q11,Q22,HL1,APL,AL,SL,NR,IBAR,
     $ DT,FUNF(L))/DFFUN(HL1,APL,AL,NR,IBAR,DT,FUNF(L)))
      DDFUNF=FUNF(L+1)-FUNF(L)
      DABS=ABS(DDFUNF)
      IF(DABS.GT.ERR5)THEN
      GOTO 1500
      ELSEIF(DABS.LE.ERR5)THEN
      NNL=L+1
      GOTO 1501
      ENDIF
 1500 CONTINUE
 1501 CONTINUE
      HL2=FUNF(L+1)
      QO2=(ALP/NR)*(HL2**(5/3))*(SLAKE**0.5)
      RETURN
      END
C**
C** NOW SUBROUTINE PLOT USES THE OUTLET DISCHARGES TO PLOT
C** THE FLOW HYDROGRAPH FOR THE WEEK CONSIDERED.
C**
      SUBROUTINE PLOT(QOUTO)
      CHARACTER*1 DISCHA(50)
      REAL QOUTO(168)
      INTEGER TIME(168),TIMEL(168),IQOUT(168)
      DATA DISCHA/50*' '/
C** WRITE A HEADING FOR TIME AND DISCHARGE
      DO 145 JJ=1,168
      TIMEL(JJ)=JJ
  145 CONTINUE
```

```
      WRITE(7,151)
      WRITE(7,152)
      DO 153 I=1,168
      IQOUT(I)=INT(QOUTO(I)+0.5)
      DISCHA(IQOUT(I))='*'
      WRITE(7,154) TIMEL(I),QOUTO(I),'I',DISCHA
      DISCHA(IQOUT(I))=' '
 153  CONTINUE
 151  FORMAT(1X,'TIME',5X,'DISCHARGE Q')
 152  FORMAT(2X,'IN Hr',5X,'IN M3/S')
 154  FORMAT(1X,I4,1X,F8.4,1X,A,1X,50A)
      RETURN
      END
```

APPENDIX C
LISTING OF TROPICS OUTPUT

```
********************
*THIS IS THE OUTPUT*
*       OF         *
*    TROPICS       *
********************

BASIN NAME: FAJARDO BASIN
BASIN AREA:       69.00 km2


ORIGINAL DISCHARGES DATA USED FOR MODEL VERIFICATION
                  UNITS = m3/s


  9.57   3.71   2.38   0.91   0.54   1.36  13.82


PRECIPITATION INPUT DATA;  UNITS : m/hr
168 HOURLY DATA VALUES RECORDED

0.000 0.000 0.000 0.000 0.000 0.250 0.000 0.000 0.000 0.000
0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000
0.000 0.000 0.760 0.250 0.510 0.000 0.000 0.000 0.000 0.000
0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 1.020 2.030
0.760 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000
0.000 0.000 0.000 0.000 0.000 1.270 0.000 0.000 0.250 0.000
0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.510 0.000 0.000 0.000
0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000
0.000 0.250 0.000 0.000 0.000 0.250 2.030 0.000 0.000 0.000
0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.250
0.000 0.250
0.000 1.270 1.020 0.250 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000
0.000 0.000 0.000 0.000 0.000 0.250 0.000 0.000 0.000 0.000
0.000 0.000
```

```
TIME(hr)=  PRECIPITATION (m/hr)=

          6  2.4999999E-03
         27  7.6000001E-03
         28  2.4999999E-03
         29  5.0999997E-03
         45  1.0199999E-02
         46  2.0299999E-02
         47  7.6000001E-03
         90  1.2700000E-02
         93  2.4999999E-03
        103  5.0999997E-03
        122  2.4999999E-03
        126  2.4999999E-03
        127  2.0299999E-02
        142  2.4999999E-03
        144  2.4999999E-03
        146  1.2700000E-02
        147  1.0199999E-02
        148  2.4999999E-03
        162  2.4999999E-03
NCOUNT=             12

THIS IS THE OUTPUT FROM REORD
   TIME(hr), RAIN(m/hr)


          6  2.4999999E-03
         27  7.6000001E-03
         28  2.4999999E-03
         29  5.0999997E-03
         45  1.0199999E-02
         46  2.0299999E-02
         47  7.6000001E-03
         90  1.2700000E-02
         93  2.4999999E-03
        103  5.0999997E-03
        122  2.4999999E-03
        126  2.4999999E-03
        127  2.0299999E-02
        142  2.4999999E-03
        144  2.4999999E-03
        146  1.2700000E-02
        147  1.0199999E-02
        148  2.4999999E-03
          0  0.0000000E+00
        162  2.4999999E-03

NEWC=            1
```

```
NEWC=             2
NEWC=             3
NEWC=             4
NEWC=             5
NEWC=             6
NEWC=             7
NEWC=             8
NEWC=             9
NEWC=            10
NEWC=            11
NEWC=            12

RAIN AND TIME FOR PROGRAM
     hr      m/hr

      6    0.00250
     27    0.00760
     28    0.00250
     29    0.00510
     45    0.01020
     46    0.02030
     47    0.00760
     90    0.01270
     93    0.00250
    103    0.00510
    122    0.00250
    126    0.00250
    127    0.02030
    142    0.00250
    144    0.00250
    146    0.01270
    147    0.01020
    148    0.00250
    162    0.00250

WEEKLY TEMPERATURE AND EVAPORATION INPUT DATA
 TMIN    TMAX  CSOLRA JULDAY
          UNITS:

  O C     O C  mm/day

 20.00  30.00    5.24 134.00
 22.20  30.00    5.24 135.00
 22.20  29.40    5.24 136.00
 22.80  30.60    5.24 137.00
 22.20  31.10    5.24 138.00
 22.20  30.60    5.24 139.00
 19.40  30.60    5.24 140.00
```

```
TEMPERATURE VALUES
IN DEGREES CENTIGRADES O C

  20.17011
  20.66937
  21.46375
  22.49913
  23.70494
  24.99900
  26.29313
  27.49914
  28.53483
  29.32963
  29.82937
  30.00000
  29.82988
  29.33061
  28.53622
  27.50084
  26.29503
  25.00096
  23.70683
  22.50083
  21.46514
  20.67035
  20.17062
  20.00000
  22.33269
  22.72211
  23.34173
  24.14932
  25.08985
  26.09922
  27.10864
  28.04933
  28.85717
  29.47711
  29.86691
  30.00000
  29.86731
  29.47788
  28.85825
  28.05066
  27.11012
  26.10075
  25.09133
  24.15065
  23.34281
  22.72287
  22.33308
  22.20000
  22.32248
```

```
22.68195
23.25390
23.99937
24.86756
25.79928
26.73106
27.59938
28.34508
28.91734
29.27715
29.40000
29.27752
28.91804
28.34608
27.60061
26.73242
25.80069
24.86892
24.00060
23.25490
22.68265
22.32285
22.20000
22.93268
23.32211
23.94173
24.74932
25.68985
26.69922
27.70864
28.64933
29.45717
30.07712
30.46691
30.60000
30.46731
30.07788
29.45825
28.65066
27.71012
26.70075
25.69133
24.75065
23.94281
23.32287
22.93308
22.80000
22.35140
22.79574
23.50274
24.42423
25.49739
```

```
26.64911
27.80089
28.87424
29.79600
30.50337
30.94814
31.10000
30.94860
30.50425
29.79724
28.87575
27.80258
26.65086
25.49908
24.42574
23.50398
22.79661
22.35185
22.20000
22.34289
22.76227
23.42955
24.29927
25.31215
26.39916
27.48623
28.49928
29.36926
30.03689
30.45668
30.60000
30.45710
30.03772
29.37043
28.50071
27.48783
26.40081
25.31374
24.30070
23.43072
22.76310
22.34332
22.20000
19.59052
20.14969
21.03940
22.19902
23.54953
24.99888
26.44831
27.79904
28.95901
```

```
   29.84919
   30.40890
   30.60000
   30.40947
   29.85029
   28.96057
   27.80094
   26.45043
   25.00108
   23.55165
   22.20093
   21.04096
   20.15079
   19.59109
   19.40000


EVAPORATION VALUES IN m/day

  1.4093027E-06
  1.4565468E-06
  1.5346135E-06
  1.6419203E-06
  1.7752269E-06
  1.9288643E-06
  2.0941491E-06
  2.2593163E-06
  2.4102208E-06
  2.5319878E-06
  2.6113023E-06
  2.6388775E-06
  2.6113851E-06
  2.5321444E-06
  2.4104340E-06
  2.2595584E-06
  2.0944051E-06
  1.9291097E-06
  1.7754477E-06
  1.6421039E-06
  1.5347551E-06
  1.4566413E-06
  1.4093516E-06
  1.3935197E-06
  1.6242368E-06
  1.6658826E-06
  1.7341015E-06
  1.8267195E-06
  1.9400784E-06
  2.0686120E-06
  2.2046206E-06
  2.3384071E-06
  2.4589704E-06
```

```
2.5551701E-06
2.6173484E-06
2.6388775E-06
2.6174075E-06
2.5552940E-06
2.4591334E-06
2.3386046E-06
2.2048250E-06
2.0688117E-06
1.9402621E-06
1.8268738E-06
1.7342232E-06
1.6659671E-06
1.6242763E-06
1.6102617E-06
1.6231562E-06
1.6615458E-06
1.7242866E-06
1.8092024E-06
1.9127385E-06
2.0296554E-06
2.1528440E-06
2.2735512E-06
2.3819271E-06
2.4681656E-06
2.5237855E-06
2.5430284E-06
2.5238435E-06
2.4682715E-06
2.3820728E-06
2.2737204E-06
2.1530341E-06
2.0298392E-06
1.9129081E-06
1.8093459E-06
1.7243991E-06
1.6616201E-06
1.6231976E-06
1.6102617E-06
1.6887961E-06
1.7319062E-06
1.8025073E-06
1.8983395E-06
2.0156033E-06
2.1485323E-06
2.2891502E-06
2.4274404E-06
2.5520319E-06
2.6514238E-06
2.7156541E-06
2.7378928E-06
2.7157205E-06
```

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2.6515477E-06
2.5521958E-06
2.4276408E-06
2.2893601E-06
2.1487397E-06
2.0157950E-06
1.8984996E-06
1.8026303E-06
1.7319907E-06
1.6888375E-06
1.6743259E-06
1.6262169E-06
1.6738645E-06
1.7522289E-06
1.8592315E-06
1.9911040E-06
2.1417518E-06
2.3023958E-06
2.4615770E-06
2.6059365E-06
2.7217345E-06
2.7968385E-06
2.8228962E-06
2.7969127E-06
2.7218762E-06
2.6061377E-06
2.4618055E-06
2.3026400E-06
2.1419876E-06
1.9913152E-06
1.8594151E-06
1.7523683E-06
1.6739576E-06
1.6262634E-06
1.6102617E-06
1.6253189E-06
1.6702322E-06
1.7439683E-06
1.8443917E-06
1.9677627E-06
2.1082305E-06
2.2574884E-06
2.4048986E-06
2.5382012E-06
2.6448720E-06
2.7139463E-06
2.7378928E-06
2.7140184E-06
2.6450043E-06
2.5383824E-06
2.4051096E-06
2.2577115E-06
```

```
 2.1084516E-06
 1.9679669E-06
 1.8445623E-06
 1.7441017E-06
 1.6703221E-06
 1.6253620E-06
 1.6102617E-06
 1.3561661E-06
 1.4074010E-06
 1.4924625E-06
 1.6101567E-06
 1.7575292E-06
 1.9288507E-06
 2.1147837E-06
 2.3021332E-06
 2.4745530E-06
 2.6144885E-06
 2.7060078E-06
 2.7378928E-06
 2.7061042E-06
 2.6146672E-06
 2.4747876E-06
 2.3024006E-06
 2.1150677E-06
 1.9291197E-06
 1.7577687E-06
 1.6103568E-06
 1.4926160E-06
 1.4075029E-06
 1.3562199E-06
 1.3390933E-06

FIRST INTERCEPTION INPUT DATA
AREA: ALL
UNITS:

  km2

  1.00
  1.00
  1.00
  1.40
  1.00
  1.00
  1.40
  1.40
  1.00
  2.50
  1.40
  1.90
  0.50
  1.00
```

```
   1.00
   1.00
   1.00
   1.00
   1.00
   1.00
   1.20
   0.80
   1.70
   1.00
   1.00
   1.00
   2.50
   1.40
   1.40
   1.90
   0.50
   1.00
   1.00
   1.00
   0.80
   1.00
   1.00
   1.60
   1.90
   1.90
   1.60
   1.90
   1.40
   1.40
   1.40
   1.40
   1.00
   1.00
   1.00
   1.00
   1.00
   1.00
   1.00
   1.40
   1.00


SECOND INTERCEPTION INPUT DATA
  DS        M
    UNITS:

  cm  NUMBER OF TREES/ha

  10.0       6000
  20.0       1700
  30.0         700
  40.0         400
  50.0         250
  60.0         180
  70.0         160
  80.0         100
  90.0          70
 100.0          30


INFILTRATION AND DEPRESSION STORAGE INPUT DATA
 RATE    WACS   SAV     DL        WIC      HKS         DE
                       UNITS:

 %/hr             m      m            cm/hr      m

0.0830 0.43 0.0534  0.10   0.10  0.1178  0.1750
0.0830 0.43 0.0534  0.10   0.10  0.1178  0.1750
0.0830 0.43 0.0534  0.10   0.10  0.1178  0.1750
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0002 0.41 0.2772  0.60   0.20  0.0003  0.2360
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0002 0.41 0.2772  0.60   0.20  0.0003  0.2360
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0002 0.41 0.2772  0.60   0.20  0.0003  0.2360
0.0002 0.41 0.2772  0.60   0.20  0.0003  0.2360
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0002 0.41 0.2772  0.60   0.20  0.0003  0.2360
```

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0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0010 0.45 0.2800  0.50   0.20  0.0004  0.2300
0.0002 0.41 0.2772  0.60   0.20  0.0003  0.2360
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0046 0.49 0.1700  0.30   0.20  0.0065  0.2400
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030
0.0024 0.44 0.0900  0.10   0.20  0.0034  0.2030

FOR ELEMENT # =            1

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

         6   0.0000000E+00
        27   2.6000002E-03
        28   1.9816963E-03
        29   6.0559385E-03
        45   5.1999995E-03
        46   2.1314906E-02
        47   2.0585753E-02
        90   7.7000000E-03
        93   0.0000000E+00
       103   9.9999830E-05
       122   0.0000000E+00
       126   0.0000000E+00
       127   1.6774241E-02
       142   0.0000000E+00
       144   0.0000000E+00
       146   7.7000000E-03
       147   1.2689150E-02
       148   1.1004057E-02
       162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.1205049
         27   0.0000000E+00   0.1205049
         28   0.0000000E+00   0.1205049
         29   0.0000000E+00   0.1205049
         45   0.0000000E+00   0.1205049
         46   0.0000000E+00   0.1205049
         47   0.0000000E+00   0.1205049
         90   0.0000000E+00   0.1205049
         93   0.0000000E+00   0.1205049
        103   0.0000000E+00   0.1205049
        122   0.0000000E+00   0.1205049
        126   0.0000000E+00   0.1205049
        127   0.0000000E+00   0.1205049
        142   0.0000000E+00   0.1205049
        144   0.0000000E+00   0.1205049
        146   0.0000000E+00   0.1205049
        147   0.0000000E+00   0.1205049
        148   0.0000000E+00   0.1205049
        162   0.0000000E+00   0.1205049

FOR ELEMENT # =           2

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   1.9816963E-03
         29   6.0559385E-03
         45   5.1999995E-03
         46   2.1314906E-02
         47   2.0585753E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6774241E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.2689150E-02
        148   1.1004057E-02
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.1205049
         27  0.0000000E+00  0.1205049
         28  0.0000000E+00  0.1205049
         29  0.0000000E+00  0.1205049
         45  0.0000000E+00  0.1205049
         46  0.0000000E+00  0.1205049
         47  0.0000000E+00  0.1205049
         90  0.0000000E+00  0.1205049
         93  0.0000000E+00  0.1205049
        103  0.0000000E+00  0.1205049
        122  0.0000000E+00  0.1205049
        126  0.0000000E+00  0.1205049
        127  0.0000000E+00  0.1205049
        142  0.0000000E+00  0.1205049
        144  0.0000000E+00  0.1205049
        146  0.0000000E+00  0.1205049
        147  0.0000000E+00  0.1205049
        148  0.0000000E+00  0.1205049
        162  0.0000000E+00  0.1205049

FOR ELEMENT # =           3

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.1205049
         27  0.0000000E+00  0.1205049
         28  0.0000000E+00  0.1205049
         29  0.0000000E+00  0.1205049
         45  0.0000000E+00  0.1205049
         46  0.0000000E+00  0.1205049
         47  0.0000000E+00  0.1205049
         90  0.0000000E+00  0.1205049
         93  0.0000000E+00  0.1205049
        103  0.0000000E+00  0.1205049
        122  0.0000000E+00  0.1205049
        126  0.0000000E+00  0.1205049
        127  0.0000000E+00  0.1205049
        142  0.0000000E+00  0.1205049
        144  0.0000000E+00  0.1205049
        146  0.0000000E+00  0.1205049
        147  0.0000000E+00  0.1205049
        148  0.0000000E+00  0.1205049
        162  0.0000000E+00  0.1205049

FOR ELEMENT # =           4

THE CANOPY DENSITY=
 0.4212120

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  7.0121151E-04
         29  4.3542413E-03
         45  5.1999995E-03
         46  1.9596362E-02
         47  1.5446967E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6353030E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.0549393E-02
        148  7.1457550E-03
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6  0.0000000E+00  4.5040000E-04
         27  0.0000000E+00  4.5040000E-04
         28  0.0000000E+00  4.5040000E-04
         29  0.0000000E+00  4.5040000E-04
         45  0.0000000E+00  4.5040000E-04
         46  0.0000000E+00  4.5040000E-04
         47  0.0000000E+00  4.5040000E-04
         90  0.0000000E+00  4.5040000E-04
         93  0.0000000E+00  4.5040000E-04
        103  0.0000000E+00  4.5040000E-04
        122  0.0000000E+00  4.5040000E-04
        126  0.0000000E+00  4.5040000E-04
        127  0.0000000E+00  4.5040000E-04
        142  0.0000000E+00  4.5040000E-04
        144  0.0000000E+00  4.5040000E-04
        146  0.0000000E+00  4.5040000E-04
        147  0.0000000E+00  4.5040000E-04
        148  0.0000000E+00  4.5040000E-04
        162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =            5

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  4.5040000E-04
         27  0.0000000E+00  4.5040000E-04
         28  0.0000000E+00  4.5040000E-04
         29  0.0000000E+00  4.5040000E-04
         45  0.0000000E+00  4.5040000E-04
         46  0.0000000E+00  4.5040000E-04
         47  0.0000000E+00  4.5040000E-04
         90  0.0000000E+00  4.5040000E-04
         93  0.0000000E+00  4.5040000E-04
        103  0.0000000E+00  4.5040000E-04
        122  0.0000000E+00  4.5040000E-04
        126  0.0000000E+00  4.5040000E-04
        127  0.0000000E+00  4.5040000E-04
        142  0.0000000E+00  4.5040000E-04
        144  0.0000000E+00  4.5040000E-04
        146  0.0000000E+00  4.5040000E-04
        147  0.0000000E+00  4.5040000E-04
        148  0.0000000E+00  4.5040000E-04
        162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =            6

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6  0.0000000E+00  4.5040000E-04
         27  0.0000000E+00  4.5040000E-04
         28  0.0000000E+00  4.5040000E-04
         29  0.0000000E+00  4.5040000E-04
         45  0.0000000E+00  4.5040000E-04
         46  0.0000000E+00  4.5040000E-04
         47  0.0000000E+00  4.5040000E-04
         90  0.0000000E+00  4.5040000E-04
         93  0.0000000E+00  4.5040000E-04
        103  0.0000000E+00  4.5040000E-04
        122  0.0000000E+00  4.5040000E-04
        126  0.0000000E+00  4.5040000E-04
        127  0.0000000E+00  4.5040000E-04
        142  0.0000000E+00  4.5040000E-04
        144  0.0000000E+00  4.5040000E-04
        146  0.0000000E+00  4.5040000E-04
        147  0.0000000E+00  4.5040000E-04
        148  0.0000000E+00  4.5040000E-04
        162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =             7

THE CANOPY DENSITY=
 0.4212120

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  7.0121151E-04
         29  4.3542413E-03
         45  5.1999995E-03
         46  1.9596362E-02
         47  1.5446967E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6353030E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.0549393E-02
        148  7.1457550E-03
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  4.5040000E-04
         27  0.0000000E+00  4.5040000E-04
         28  0.0000000E+00  4.5040000E-04
         29  0.0000000E+00  4.5040000E-04
         45  0.0000000E+00  4.5040000E-04
         46  0.0000000E+00  4.5040000E-04
         47  0.0000000E+00  4.5040000E-04
         90  0.0000000E+00  4.5040000E-04
         93  0.0000000E+00  4.5040000E-04
        103  0.0000000E+00  4.5040000E-04
        122  0.0000000E+00  4.5040000E-04
        126  0.0000000E+00  4.5040000E-04
        127  0.0000000E+00  4.5040000E-04
        142  0.0000000E+00  4.5040000E-04
        144  0.0000000E+00  4.5040000E-04
        146  0.0000000E+00  4.5040000E-04
        147  0.0000000E+00  4.5040000E-04
        148  0.0000000E+00  4.5040000E-04
        162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =           8

THE CANOPY DENSITY=
 0.4212120

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  7.0121151E-04
         29  4.3542413E-03
         45  5.1999995E-03
         46  1.9596362E-02
         47  1.5446967E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6353030E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.0549393E-02
        148  7.1457550E-03
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  3.5346402E-03
         27  0.0000000E+00  3.5346402E-03
         28  0.0000000E+00  3.5346402E-03
         29  0.0000000E+00  3.5346402E-03
         45  0.0000000E+00  3.5346402E-03
         46  0.0000000E+00  3.5346402E-03
         47  0.0000000E+00  3.5346402E-03
         90  0.0000000E+00  3.5346402E-03
         93  0.0000000E+00  3.5346402E-03
        103  0.0000000E+00  3.5346402E-03
        122  0.0000000E+00  3.5346402E-03
        126  0.0000000E+00  3.5346402E-03
        127  0.0000000E+00  3.5346402E-03
        142  0.0000000E+00  3.5346402E-03
        144  0.0000000E+00  3.5346402E-03
        146  0.0000000E+00  3.5346402E-03
        147  0.0000000E+00  3.5346402E-03
        148  0.0000000E+00  3.5346402E-03
        162  0.0000000E+00  3.5346402E-03

FOR ELEMENT # =            9

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   4.5040000E-04
         27   0.0000000E+00   4.5040000E-04
         28   0.0000000E+00   4.5040000E-04
         29   0.0000000E+00   4.5040000E-04
         45   0.0000000E+00   4.5040000E-04
         46   0.0000000E+00   4.5040000E-04
         47   0.0000000E+00   4.5040000E-04
         90   0.0000000E+00   4.5040000E-04
         93   0.0000000E+00   4.5040000E-04
        103   0.0000000E+00   4.5040000E-04
        122   0.0000000E+00   4.5040000E-04
        126   0.0000000E+00   4.5040000E-04
        127   0.0000000E+00   4.5040000E-04
        142   0.0000000E+00   4.5040000E-04
        144   0.0000000E+00   4.5040000E-04
        146   0.0000000E+00   4.5040000E-04
        147   0.0000000E+00   4.5040000E-04
        148   0.0000000E+00   4.5040000E-04
        162   0.0000000E+00   4.5040000E-04

FOR ELEMENT # =           10

THE CANOPY DENSITY=
 0.2358787

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000005E-03
         28   0.0000000E+00
         29   2.4823754E-03
         45   5.2000000E-03
         46   1.7705964E-02
         47   9.7943023E-03
         90   7.7000004E-03
         93   0.0000000E+00
        103   1.0000006E-04
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.5889697E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000004E-03
        147   8.1956601E-03
        148   2.9016230E-03
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
   TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

           6  0.0000000E+00  4.5040000E-04
          27  0.0000000E+00  4.5040000E-04
          28  0.0000000E+00  4.5040000E-04
          29  0.0000000E+00  4.5040000E-04
          45  0.0000000E+00  4.5040000E-04
          46  0.0000000E+00  4.5040000E-04
          47  0.0000000E+00  4.5040000E-04
          90  0.0000000E+00  4.5040000E-04
          93  0.0000000E+00  4.5040000E-04
         103  0.0000000E+00  4.5040000E-04
         122  0.0000000E+00  4.5040000E-04
         126  0.0000000E+00  4.5040000E-04
         127  0.0000000E+00  4.5040000E-04
         142  0.0000000E+00  4.5040000E-04
         144  2.1496005E-03  4.5040000E-04
         146  0.0000000E+00  4.5040000E-04
         147  0.0000000E+00  4.5040000E-04
         148  0.0000000E+00  4.5040000E-04
         162  0.0000000E+00  4.5040000E-04

 FOR ELEMENT # =          11

 THE CANOPY DENSITY=
  0.4212120

 THE COMPUTED THROUGHFALL VALUES=

   TIME(hr)   THROUGHFALL (m/hr)

           6  0.0000000E+00
          27  2.6000002E-03
          28  7.0121151E-04
          29  4.3542413E-03
          45  5.1999995E-03
          46  1.9596362E-02
          47  1.5446967E-02
          90  7.7000000E-03
          93  0.0000000E+00
         103  9.9999830E-05
         122  0.0000000E+00
         126  0.0000000E+00
         127  1.6353030E-02
         142  0.0000000E+00
         144  0.0000000E+00
         146  7.7000000E-03
         147  1.0549393E-02
         148  7.1457550E-03
         162  0.0000000E+00

 THE COMPUTED INFILTRATION VALUES=
   TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6   0.0000000E+00  0.0000000E+00
         27   0.0000000E+00  0.0000000E+00
         28   0.0000000E+00  0.0000000E+00
         29   0.0000000E+00  0.0000000E+00
         45   0.0000000E+00  0.0000000E+00
         46   0.0000000E+00  0.0000000E+00
         47   0.0000000E+00  0.0000000E+00
         90   0.0000000E+00  0.0000000E+00
         93   0.0000000E+00  0.0000000E+00
        103   0.0000000E+00  0.0000000E+00
        122   0.0000000E+00  0.0000000E+00
        126   0.0000000E+00  0.0000000E+00
        127   0.0000000E+00  0.0000000E+00
        142   0.0000000E+00  0.0000000E+00
        144   0.0000000E+00  4.5040000E-04
        146   0.0000000E+00  4.5040000E-04
        147   0.0000000E+00  4.5040000E-04
        148   0.0000000E+00  4.5040000E-04
        162   0.0000000E+00  4.5040000E-04

FOR ELEMENT # =           12

THE CANOPY DENSITY=
 0.3103667

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  0.0000000E+00
         29  3.2347040E-03
         45  5.2000000E-03
         46  1.8465741E-02
         47  1.2066186E-02
         90  7.6999995E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6075917E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.6999995E-03
        147  9.1416575E-03
        148  4.6073981E-03
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  0.0000000E+00  0.0000000E+00
         46  0.0000000E+00  0.0000000E+00
         47  0.0000000E+00  0.0000000E+00
         90  0.0000000E+00  0.0000000E+00
         93  0.0000000E+00  0.0000000E+00
        103  0.0000000E+00  0.0000000E+00
        122  0.0000000E+00  0.0000000E+00
        126  0.0000000E+00  0.0000000E+00
        127  0.0000000E+00  0.0000000E+00
        142  0.0000000E+00  0.0000000E+00
        144  0.0000000E+00  4.5040000E-04
        146  0.0000000E+00  4.5040000E-04
        147  0.0000000E+00  4.5040000E-04
        148  0.0000000E+00  4.5040000E-04
        162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =           13

THE CANOPY DENSITY=
  1.000000

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  5.1000006E-03
         29  1.0200000E-02
         45  5.1999995E-03
         46  2.5500000E-02
         47  3.3100002E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.7800000E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.7900001E-02
        148  2.0400001E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
 TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

         6   0.0000000E+00   0.0000000E+00
        27   0.0000000E+00   0.0000000E+00
        28   0.0000000E+00   0.0000000E+00
        29   0.0000000E+00   0.0000000E+00
        45   0.0000000E+00   0.0000000E+00
        46   0.0000000E+00   0.0000000E+00
        47   0.0000000E+00   0.0000000E+00
        90   0.0000000E+00   0.0000000E+00
        93   0.0000000E+00   0.0000000E+00
       103   0.0000000E+00   0.0000000E+00
       122   0.0000000E+00   0.0000000E+00
       126   0.0000000E+00   0.0000000E+00
       127   0.0000000E+00   0.0000000E+00
       142   0.0000000E+00   0.0000000E+00
       144   0.0000000E+00   4.5040000E-04
       146   0.0000000E+00   4.5040000E-04
       147   0.0000000E+00   4.5040000E-04
       148   0.0000000E+00   4.5040000E-04
       162   0.0000000E+00   4.5040000E-04

FOR ELEMENT # =          14

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

         6   0.0000000E+00
        27   2.6000002E-03
        28   1.9816963E-03
        29   6.0559385E-03
        45   5.1999995E-03
        46   2.1314906E-02
        47   2.0585753E-02
        90   7.7000000E-03
        93   0.0000000E+00
       103   9.9999830E-05
       122   0.0000000E+00
       126   0.0000000E+00
       127   1.6774241E-02
       142   0.0000000E+00
       144   0.0000000E+00
       146   7.7000000E-03
       147   1.2689150E-02
       148   1.1004057E-02
       162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  0.0000000E+00  0.0000000E+00
         46  0.0000000E+00  0.0000000E+00
         47  0.0000000E+00  0.0000000E+00
         90  0.0000000E+00  0.0000000E+00
         93  0.0000000E+00  0.0000000E+00
        103  2.1496003E-03  4.5040000E-04
        122  0.0000000E+00  4.5040000E-04
        126  0.0000000E+00  4.5040000E-04
        127  0.0000000E+00  4.5040000E-04
        142  0.0000000E+00  4.5040000E-04
        144  0.0000000E+00  4.5040000E-04
        146  0.0000000E+00  4.5040000E-04
        147  0.0000000E+00  4.5040000E-04
        148  0.0000000E+00  4.5040000E-04
        162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =           15

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   0.0000000E+00
         93   0.0000000E+00   0.0000000E+00
        103   5.7218429E-03   3.3409562E-04
        122   0.0000000E+00   3.3409562E-04
        126   0.0000000E+00   3.3409562E-04
        127   0.0000000E+00   3.3409562E-04
        142   0.0000000E+00   3.3409562E-04
        144   0.0000000E+00   3.3409562E-04
        146   0.0000000E+00   3.3409562E-04
        147   0.0000000E+00   3.3409562E-04
        148   0.0000000E+00   3.3409562E-04
        162   4.8659043E-03   3.3409562E-04

FOR ELEMENT # =            16

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   1.9816963E-03
         29   6.0559385E-03
         45   5.1999995E-03
         46   2.1314906E-02
         47   2.0585753E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6774241E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.2689150E-02
        148   1.1004057E-02
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   2.1496005E-03   4.5040000E-04
         93   1.5312964E-03   4.5040000E-04
        103   0.0000000E+00   4.5040000E-04
        122   0.0000000E+00   4.5040000E-04
        126   0.0000000E+00   4.5040000E-04
        127   0.0000000E+00   4.5040000E-04
        142   0.0000000E+00   4.5040000E-04
        144   0.0000000E+00   4.5040000E-04
        146   0.0000000E+00   4.5040000E-04
        147   0.0000000E+00   4.5040000E-04
        148   0.0000000E+00   4.5040000E-04
        162   0.0000000E+00   4.5040000E-04

FOR ELEMENT # =           17

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   0.0000000E+00
         93   0.0000000E+00   4.5040000E-04
        103   0.0000000E+00   4.5040000E-04
        122   0.0000000E+00   4.5040000E-04
        126   0.0000000E+00   4.5040000E-04
        127   0.0000000E+00   4.5040000E-04
        142   0.0000000E+00   4.5040000E-04
        144   0.0000000E+00   4.5040000E-04
        146   1.9145962E-02   4.5040000E-04
        147   0.0000000E+00   4.5040000E-04
        148   0.0000000E+00   4.5040000E-04
        162   0.0000000E+00   4.5040000E-04

FOR ELEMENT # =            18

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   1.9816963E-03
         29   6.0559385E-03
         45   5.1999995E-03
         46   2.1314906E-02
         47   2.0585753E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6774241E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.2689150E-02
        148   1.1004057E-02
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  0.0000000E+00  0.0000000E+00
         46  0.0000000E+00  0.0000000E+00
         47  0.0000000E+00  0.0000000E+00
         90  0.0000000E+00  0.0000000E+00
         93  0.0000000E+00  0.0000000E+00
        103  0.0000000E+00  0.0000000E+00
        122  0.0000000E+00  0.0000000E+00
        126  0.0000000E+00  0.0000000E+00
        127  0.0000000E+00  0.0000000E+00
        142  0.0000000E+00  0.0000000E+00
        144  0.0000000E+00  0.0000000E+00
        146  0.0000000E+00  3.5346402E-03
        147  0.0000000E+00  3.5346402E-03
        148  0.0000000E+00  3.5346402E-03
        162  0.0000000E+00  3.5346402E-03

FOR ELEMENT # =          19

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (m/hr)   EXCESS(m/hr)   INFILT(m/hr)

           6  0.0000000E+00  0.0000000E+00
          27  0.0000000E+00  0.0000000E+00
          28  0.0000000E+00  0.0000000E+00
          29  0.0000000E+00  0.0000000E+00
          45  0.0000000E+00  0.0000000E+00
          46  0.0000000E+00  0.0000000E+00
          47  0.0000000E+00  0.0000000E+00
          90  0.0000000E+00  0.0000000E+00
          93  0.0000000E+00  0.0000000E+00
         103  0.0000000E+00  0.0000000E+00
         122  0.0000000E+00  0.0000000E+00
         126  0.0000000E+00  0.0000000E+00
         127  0.0000000E+00  0.0000000E+00
         142  0.0000000E+00  0.0000000E+00
         144  0.0000000E+00  0.0000000E+00
         146  0.0000000E+00  4.5040000E-04
         147  0.0000000E+00  4.5040000E-04
         148  0.0000000E+00  4.5040000E-04
         162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =           20

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

           6  0.0000000E+00
          27  2.6000002E-03
          28  1.9816963E-03
          29  6.0559385E-03
          45  5.1999995E-03
          46  2.1314906E-02
          47  2.0585753E-02
          90  7.7000000E-03
          93  0.0000000E+00
         103  9.9999830E-05
         122  0.0000000E+00
         126  0.0000000E+00
         127  1.6774241E-02
         142  0.0000000E+00
         144  0.0000000E+00
         146  7.7000000E-03
         147  1.2689150E-02
         148  1.1004057E-02
         162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
   TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

           6  0.0000000E+00  0.0000000E+00
          27  0.0000000E+00  0.0000000E+00
          28  0.0000000E+00  0.0000000E+00
          29  0.0000000E+00  0.0000000E+00
          45  0.0000000E+00  0.0000000E+00
          46  0.0000000E+00  0.0000000E+00
          47  0.0000000E+00  0.0000000E+00
          90  0.0000000E+00  0.0000000E+00
          93  0.0000000E+00  0.0000000E+00
         103  0.0000000E+00  0.0000000E+00
         122  1.6653594E-03  3.5346402E-03
         126  0.0000000E+00  0.0000000E+00
         127  6.2596621E-03  3.5346402E-03
         142  0.0000000E+00  3.5346402E-03
         144  0.0000000E+00  3.5346402E-03
         146  0.0000000E+00  3.5346402E-03
         147  0.0000000E+00  3.5346402E-03
         148  0.0000000E+00  3.5346402E-03
         162  0.0000000E+00  3.5346402E-03

FOR ELEMENT # =           21

THE CANOPY DENSITY=
 0.4914140

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

           6  0.0000000E+00
          27  2.6000005E-03
          28  1.2347471E-03
          29  5.0632819E-03
          45  5.1999995E-03
          46  2.0312423E-02
          47  1.7588127E-02
          90  7.7000004E-03
          93  0.0000000E+00
         103  9.9999830E-05
         122  0.0000000E+00
         126  0.0000000E+00
         127  1.6528536E-02
         142  0.0000000E+00
         144  0.0000000E+00
         146  7.7000004E-03
         147  1.1440958E-02
         148  8.7533817E-03
         162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
   TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   0.0000000E+00
         93   0.0000000E+00   0.0000000E+00
        103   0.0000000E+00   0.0000000E+00
        122   0.0000000E+00   0.0000000E+00
        126   0.0000000E+00   0.0000000E+00
        127   0.0000000E+00   3.5346402E-03
        142   0.0000000E+00   3.5346402E-03
        144   0.0000000E+00   3.5346402E-03
        146   0.0000000E+00   3.5346402E-03
        147   0.0000000E+00   3.5346402E-03
        148   0.0000000E+00   3.5346402E-03
        162   0.0000000E+00   3.5346402E-03

FOR ELEMENT # =           22

THE CANOPY DENSITY=
 0.7371210

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   3.1021202E-03
         29   7.5449226E-03
         45   5.1999995E-03
         46   2.2818634E-02
         47   2.5082191E-02
         90   7.7000004E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.7142801E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000004E-03
        147   1.4561438E-02
        148   1.4380072E-02
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  0.0000000E+00  0.0000000E+00
         46  0.0000000E+00  0.0000000E+00
         47  0.0000000E+00  0.0000000E+00
         90  0.0000000E+00  0.0000000E+00
         93  0.0000000E+00  0.0000000E+00
        103  0.0000000E+00  0.0000000E+00
        122  0.0000000E+00  0.0000000E+00
        126  0.0000000E+00  0.0000000E+00
        127  0.0000000E+00  3.5346402E-03
        142  0.0000000E+00  3.5346402E-03
        144  0.0000000E+00  3.5346402E-03
        146  0.0000000E+00  3.5346402E-03
        147  0.0000000E+00  3.5346402E-03
        148  0.0000000E+00  3.5346402E-03
        162  0.0000000E+00  3.5346402E-03

FOR ELEMENT # =           23

THE CANOPY DENSITY=
 0.3468805

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000000E-03
         28  1.3629184E-04
         29  3.6034929E-03
         45  5.1999995E-03
         46  1.8838180E-02
         47  1.3179854E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999597E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6167201E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  9.6053816E-03
        148  5.4435632E-03
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   0.0000000E+00
         93   0.0000000E+00   0.0000000E+00
        103   0.0000000E+00   0.0000000E+00
        122   0.0000000E+00   0.0000000E+00
        126   0.0000000E+00   0.0000000E+00
        127   0.0000000E+00   3.5346402E-03
        142   0.0000000E+00   3.5346402E-03
        144   0.0000000E+00   3.5346402E-03
        146   0.0000000E+00   3.5346402E-03
        147   0.0000000E+00   3.5346402E-03
        148   0.0000000E+00   3.5346402E-03
        162   0.0000000E+00   3.5346402E-03

FOR ELEMENT # =          24

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   1.9816963E-03
         29   6.0559385E-03
         45   5.1999995E-03
         46   2.1314906E-02
         47   2.0585753E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6774241E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.2689150E-02
        148   1.1004057E-02
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
   TIME (hr)    EXCESS(m/hr)     INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   0.0000000E+00
         93   0.0000000E+00   0.0000000E+00
        103   0.0000000E+00   0.0000000E+00
        122   0.0000000E+00   0.0000000E+00
        126   0.0000000E+00   0.0000000E+00
        127   0.0000000E+00   3.5346402E-03
        142   0.0000000E+00   3.5346402E-03
        144   0.0000000E+00   3.5346402E-03
        146   0.0000000E+00   3.5346402E-03
        147   0.0000000E+00   3.5346402E-03
        148   0.0000000E+00   3.5346402E-03
        162   0.0000000E+00   3.5346402E-03

 FOR ELEMENT # =             25

 THE CANOPY DENSITY=
  0.5896968

 THE COMPUTED THROUGHFALL VALUES=

   TIME(hr)     THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   1.9816963E-03
         29   6.0559385E-03
         45   5.1999995E-03
         46   2.1314906E-02
         47   2.0585753E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6774241E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.2689150E-02
        148   1.1004057E-02
        162   0.0000000E+00

 THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   0.0000000E+00
         93   0.0000000E+00   0.0000000E+00
        103   0.0000000E+00   0.0000000E+00
        122   0.0000000E+00   0.0000000E+00
        126   0.0000000E+00   0.0000000E+00
        127   0.0000000E+00   3.5346402E-03
        142   0.0000000E+00   3.5346402E-03
        144   0.0000000E+00   3.5346402E-03
        146   0.0000000E+00   3.5346402E-03
        147   0.0000000E+00   3.5346402E-03
        148   0.0000000E+00   3.5346402E-03
        162   0.0000000E+00   3.5346402E-03

FOR ELEMENT # =           26

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   1.9816963E-03
         29   6.0559385E-03
         45   5.1999995E-03
         46   2.1314906E-02
         47   2.0585753E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6774241E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.2689150E-02
        148   1.1004057E-02
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
   TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

           6  0.0000000E+00  0.0000000E+00
          27  0.0000000E+00  0.0000000E+00
          28  0.0000000E+00  0.0000000E+00
          29  0.0000000E+00  0.0000000E+00
          45  0.0000000E+00  0.0000000E+00
          46  0.0000000E+00  0.0000000E+00
          47  0.0000000E+00  0.0000000E+00
          90  0.0000000E+00  0.0000000E+00
          93  0.0000000E+00  0.0000000E+00
         103  0.0000000E+00  0.0000000E+00
         122  0.0000000E+00  0.0000000E+00
         126  0.0000000E+00  0.0000000E+00
         127  0.0000000E+00  4.5040000E-04
         142  0.0000000E+00  4.5040000E-04
         144  0.0000000E+00  4.5040000E-04
         146  0.0000000E+00  4.5040000E-04
         147  0.0000000E+00  4.5040000E-04
         148  0.0000000E+00  4.5040000E-04
         162  0.0000000E+00  4.5040000E-04

 FOR ELEMENT # =           27

 THE CANOPY DENSITY=
  0.2358787

 THE COMPUTED THROUGHFALL VALUES=

   TIME(hr)   THROUGHFALL (m/hr)

           6  0.0000000E+00
          27  2.6000005E-03
          28  0.0000000E+00
          29  2.4823754E-03
          45  5.2000000E-03
          46  1.7705964E-02
          47  9.7943023E-03
          90  7.7000004E-03
          93  0.0000000E+00
         103  1.0000006E-04
         122  0.0000000E+00
         126  0.0000000E+00
         127  1.5889697E-02
         142  0.0000000E+00
         144  0.0000000E+00
         146  7.7000004E-03
         147  8.1956601E-03
         148  2.9016230E-03
         162  0.0000000E+00

 THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  0.0000000E+00  0.0000000E+00
         46  0.0000000E+00  0.0000000E+00
         47  0.0000000E+00  0.0000000E+00
         90  4.7495998E-03  4.5040000E-04
         93  0.0000000E+00  4.5040000E-04
        103  0.0000000E+00  4.5040000E-04
        122  0.0000000E+00  4.5040000E-04
        126  0.0000000E+00  4.5040000E-04
        127  0.0000000E+00  4.5040000E-04
        142  0.0000000E+00  4.5040000E-04
        144  0.0000000E+00  4.5040000E-04
        146  0.0000000E+00  4.5040000E-04
        147  0.0000000E+00  4.5040000E-04
        148  0.0000000E+00  4.5040000E-04
        162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =           28

THE CANOPY DENSITY=
 0.4212120

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  7.0121151E-04
         29  4.3542413E-03
         45  5.1999995E-03
         46  1.9596362E-02
         47  1.5446967E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6353030E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.0549393E-02
        148  7.1457550E-03
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (m/hr)   EXCESS(m/hr)   INFILT(m/hr)

           6  0.0000000E+00  0.0000000E+00
          27  0.0000000E+00  0.0000000E+00
          28  0.0000000E+00  0.0000000E+00
          29  0.0000000E+00  0.0000000E+00
          45  0.0000000E+00  0.0000000E+00
          46  0.0000000E+00  0.0000000E+00
          47  0.0000000E+00  0.0000000E+00
          90  0.0000000E+00  4.5040000E-04
          93  0.0000000E+00  4.5040000E-04
         103  0.0000000E+00  4.5040000E-04
         122  0.0000000E+00  4.5040000E-04
         126  0.0000000E+00  4.5040000E-04
         127  0.0000000E+00  4.5040000E-04
         142  0.0000000E+00  4.5040000E-04
         144  0.0000000E+00  4.5040000E-04
         146  0.0000000E+00  4.5040000E-04
         147  0.0000000E+00  4.5040000E-04
         148  0.0000000E+00  4.5040000E-04
         162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =           29

THE CANOPY DENSITY=
 0.4212120

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

           6  0.0000000E+00
          27  2.6000002E-03
          28  7.0121151E-04
          29  4.3542413E-03
          45  5.1999995E-03
          46  1.9596362E-02
          47  1.5446967E-02
          90  7.7000000E-03
          93  0.0000000E+00
         103  9.9999830E-05
         122  0.0000000E+00
         126  0.0000000E+00
         127  1.6353030E-02
         142  0.0000000E+00
         144  0.0000000E+00
         146  7.7000000E-03
         147  1.0549393E-02
         148  7.1457550E-03
         162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)     INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   3.3409562E-04
         93   0.0000000E+00   3.3409562E-04
        103   0.0000000E+00   3.3409562E-04
        122   0.0000000E+00   3.3409562E-04
        126   0.0000000E+00   3.3409562E-04
        127   0.0000000E+00   3.3409562E-04
        142   0.0000000E+00   3.3409562E-04
        144   0.0000000E+00   3.3409562E-04
        146   0.0000000E+00   3.3409562E-04
        147   0.0000000E+00   3.3409562E-04
        148   0.0000000E+00   3.3409562E-04
        162   0.0000000E+00   3.3409562E-04

FOR ELEMENT # =          30

THE CANOPY DENSITY=
 0.3103667

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   0.0000000E+00
         29   3.2347040E-03
         45   5.2000000E-03
         46   1.8465741E-02
         47   1.2066186E-02
         90   7.6999995E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6075917E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.6999995E-03
        147   9.1416575E-03
        148   4.6073981E-03
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (m/hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  0.0000000E+00  0.0000000E+00
         46  0.0000000E+00  0.0000000E+00
         47  0.0000000E+00  0.0000000E+00
         90  0.0000000E+00  4.5040000E-04
         93  0.0000000E+00  4.5040000E-04
        103  0.0000000E+00  4.5040000E-04
        122  0.0000000E+00  4.5040000E-04
        126  0.0000000E+00  4.5040000E-04
        127  0.0000000E+00  4.5040000E-04
        142  0.0000000E+00  4.5040000E-04
        144  0.0000000E+00  4.5040000E-04
        146  0.0000000E+00  4.5040000E-04
        147  0.0000000E+00  4.5040000E-04
        148  0.0000000E+00  4.5040000E-04
        162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =          31

THE CANOPY DENSITY=
  1.000000

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  5.1000006E-03
         29  1.0200000E-02
         45  5.1999995E-03
         46  2.5500000E-02
         47  3.3100002E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.7800000E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.7900001E-02
        148  2.0400001E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  0.0000000E+00  0.0000000E+00
         46  0.0000000E+00  0.0000000E+00
         47  2.2659048E-03  3.3409562E-04
         90  0.0000000E+00  3.3409562E-04
         93  0.0000000E+00  3.3409562E-04
        103  0.0000000E+00  3.3409562E-04
        122  0.0000000E+00  3.3409562E-04
        126  0.0000000E+00  3.3409562E-04
        127  0.0000000E+00  3.3409562E-04
        142  0.0000000E+00  3.3409562E-04
        144  0.0000000E+00  3.3409562E-04
        146  0.0000000E+00  3.3409562E-04
        147  0.0000000E+00  3.3409562E-04
        148  0.0000000E+00  3.3409562E-04
        162  0.0000000E+00  3.3409562E-04

FOR ELEMENT # =          32

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  2.2659048E-03  3.3409562E-04
         46  0.0000000E+00  3.3409562E-04
         47  1.6476008E-03  3.3409562E-04
         90  0.0000000E+00  3.3409562E-04
         93  0.0000000E+00  3.3409562E-04
        103  0.0000000E+00  3.3409562E-04
        122  0.0000000E+00  3.3409562E-04
        126  0.0000000E+00  3.3409562E-04
        127  0.0000000E+00  3.3409562E-04
        142  0.0000000E+00  3.3409562E-04
        144  0.0000000E+00  3.3409562E-04
        146  0.0000000E+00  3.3409562E-04
        147  0.0000000E+00  3.3409562E-04
        148  0.0000000E+00  3.3409562E-04
        162  0.0000000E+00  3.3409562E-04

FOR ELEMENT # =          33

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

         6   0.0000000E+00   0.0000000E+00
        27   0.0000000E+00   0.0000000E+00
        28   0.0000000E+00   0.0000000E+00
        29   0.0000000E+00   0.0000000E+00
        45   0.0000000E+00   0.0000000E+00
        46   0.0000000E+00   1.9816963E-03
        47   8.1960112E-04   3.5346402E-03
        90   0.0000000E+00   3.5346402E-03
        93   0.0000000E+00   3.5346402E-03
       103   0.0000000E+00   3.5346402E-03
       122   0.0000000E+00   3.5346402E-03
       126   0.0000000E+00   3.5346402E-03
       127   0.0000000E+00   3.5346402E-03
       142   0.0000000E+00   3.5346402E-03
       144   0.0000000E+00   3.5346402E-03
       146   0.0000000E+00   3.5346402E-03
       147   0.0000000E+00   3.5346402E-03
       148   0.0000000E+00   3.5346402E-03
       162   0.0000000E+00   3.5346402E-03

FOR ELEMENT # =           34

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

         6   0.0000000E+00
        27   2.6000002E-03
        28   1.9816963E-03
        29   6.0559385E-03
        45   5.1999995E-03
        46   2.1314906E-02
        47   2.0585753E-02
        90   7.7000000E-03
        93   0.0000000E+00
       103   9.9999830E-05
       122   0.0000000E+00
       126   0.0000000E+00
       127   1.6774241E-02
       142   0.0000000E+00
       144   0.0000000E+00
       146   7.7000000E-03
       147   1.2689150E-02
       148   1.1004057E-02
       162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (m/hr)   EXCESS(m/hr)   INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   5.6055384E-03   4.5040000E-04
         47   0.0000000E+00   4.5040000E-04
         90   0.0000000E+00   4.5040000E-04
         93   0.0000000E+00   4.5040000E-04
        103   0.0000000E+00   4.5040000E-04
        122   0.0000000E+00   4.5040000E-04
        126   0.0000000E+00   4.5040000E-04
        127   0.0000000E+00   4.5040000E-04
        142   0.0000000E+00   4.5040000E-04
        144   7.2495998E-03   4.5040000E-04
        146   0.0000000E+00   4.5040000E-04
        147   0.0000000E+00   4.5040000E-04
        148   0.0000000E+00   4.5040000E-04
        162   0.0000000E+00   4.5040000E-04

FOR ELEMENT # =          35

THE CANOPY DENSITY=
 0.7371210

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   3.1021202E-03
         29   7.5449226E-03
         45   5.1999995E-03
         46   2.2818634E-02
         47   2.5082191E-02
         90   7.7000004E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.7142801E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000004E-03
        147   1.4561438E-02
        148   1.4380072E-02
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6   0.0000000E+00  0.0000000E+00
         27   0.0000000E+00  0.0000000E+00
         28   0.0000000E+00  0.0000000E+00
         29   0.0000000E+00  0.0000000E+00
         45   7.2108270E-03  3.3409562E-04
         46   0.0000000E+00  3.3409562E-04
         47   0.0000000E+00  3.3409562E-04
         90   0.0000000E+00  3.3409562E-04
         93   0.0000000E+00  3.3409562E-04
        103   0.0000000E+00  3.3409562E-04
        122   0.0000000E+00  3.3409562E-04
        126   0.0000000E+00  3.3409562E-04
        127   0.0000000E+00  3.3409562E-04
        142   0.0000000E+00  3.3409562E-04
        144   0.0000000E+00  3.3409562E-04
        146   0.0000000E+00  3.3409562E-04
        147   0.0000000E+00  3.3409562E-04
        148   0.0000000E+00  3.3409562E-04
        162   0.0000000E+00  3.3409562E-04

FOR ELEMENT # =           36

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

         6   0.0000000E+00
        27   2.6000002E-03
        28   1.9816963E-03
        29   6.0559385E-03
        45   5.1999995E-03
        46   2.1314906E-02
        47   2.0585753E-02
        90   7.7000000E-03
        93   0.0000000E+00
       103   9.9999830E-05
       122   0.0000000E+00
       126   0.0000000E+00
       127   1.6774241E-02
       142   0.0000000E+00
       144   0.0000000E+00
       146   7.7000000E-03
       147   1.2689150E-02
       148   1.1004057E-02
       162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   3.5346402E-03
         46   0.0000000E+00   3.5346402E-03
         47   0.0000000E+00   3.5346402E-03
         90   0.0000000E+00   3.5346402E-03
         93   0.0000000E+00   3.5346402E-03
        103   0.0000000E+00   3.5346402E-03
        122   0.0000000E+00   3.5346402E-03
        126   0.0000000E+00   3.5346402E-03
        127   0.0000000E+00   3.5346402E-03
        142   0.0000000E+00   3.5346402E-03
        144   0.0000000E+00   3.5346402E-03
        146   0.0000000E+00   3.5346402E-03
        147   0.0000000E+00   3.5346402E-03
        148   0.0000000E+00   3.5346402E-03
        162   0.0000000E+00   3.5346402E-03

FOR ELEMENT # =          37

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   1.9816963E-03
         29   6.0559385E-03
         45   5.1999995E-03
         46   2.1314906E-02
         47   2.0585753E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6774241E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.2689150E-02
        148   1.1004057E-02
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

         6  0.0000000E+00  0.0000000E+00
        27  0.0000000E+00  0.0000000E+00
        28  0.0000000E+00  0.0000000E+00
        29  0.0000000E+00  0.0000000E+00
        45  0.0000000E+00  4.5040000E-04
        46  0.0000000E+00  4.5040000E-04
        47  0.0000000E+00  4.5040000E-04
        90  0.0000000E+00  4.5040000E-04
        93  0.0000000E+00  4.5040000E-04
       103  0.0000000E+00  4.5040000E-04
       122  0.0000000E+00  4.5040000E-04
       126  0.0000000E+00  4.5040000E-04
       127  0.0000000E+00  4.5040000E-04
       142  0.0000000E+00  4.5040000E-04
       144  0.0000000E+00  4.5040000E-04
       146  0.0000000E+00  4.5040000E-04
       147  0.0000000E+00  4.5040000E-04
       148  0.0000000E+00  4.5040000E-04
       162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =           38

THE CANOPY DENSITY=
 0.3685605

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

         6  0.0000000E+00
        27  2.6000005E-03
        28  3.0106027E-04
        29  3.8224615E-03
        45  5.2000000E-03
        46  1.9059317E-02
        47  1.3841095E-02
        90  7.7000004E-03
        93  0.0000000E+00
       103  1.0000006E-04
       122  0.0000000E+00
       126  0.0000000E+00
       127  1.6221400E-02
       142  0.0000000E+00
       144  0.0000000E+00
       146  7.7000004E-03
       147  9.8807197E-03
       148  5.9400364E-03
       162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  0.0000000E+00  4.5040000E-04
         46  0.0000000E+00  4.5040000E-04
         47  0.0000000E+00  4.5040000E-04
         90  0.0000000E+00  4.5040000E-04
         93  0.0000000E+00  4.5040000E-04
        103  0.0000000E+00  4.5040000E-04
        122  0.0000000E+00  4.5040000E-04
        126  0.0000000E+00  4.5040000E-04
        127  0.0000000E+00  4.5040000E-04
        142  0.0000000E+00  4.5040000E-04
        144  0.0000000E+00  4.5040000E-04
        146  0.0000000E+00  4.5040000E-04
        147  0.0000000E+00  4.5040000E-04
        148  0.0000000E+00  4.5040000E-04
        162  0.0000000E+00  4.5040000E-04

FOR ELEMENT # =           39

THE CANOPY DENSITY=
 0.3103667

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  0.0000000E+00
         29  3.2347040E-03
         45  5.2000000E-03
         46  1.8465741E-02
         47  1.2066186E-02
         90  7.6999995E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6075917E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.6999995E-03
        147  9.1416575E-03
        148  4.6073981E-03
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   4.5040000E-04
         46   0.0000000E+00   4.5040000E-04
         47   0.0000000E+00   4.5040000E-04
         90   0.0000000E+00   4.5040000E-04
         93   0.0000000E+00   4.5040000E-04
        103   0.0000000E+00   4.5040000E-04
        122   0.0000000E+00   4.5040000E-04
        126   7.2495998E-03   4.5040000E-04
        127   0.0000000E+00   4.5040000E-04
        142   0.0000000E+00   4.5040000E-04
        144   0.0000000E+00   4.5040000E-04
        146   0.0000000E+00   4.5040000E-04
        147   0.0000000E+00   4.5040000E-04
        148   0.0000000E+00   4.5040000E-04
        162   0.0000000E+00   4.5040000E-04

FOR ELEMENT # =          40

THE CANOPY DENSITY=
 0.3103667

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   0.0000000E+00
         29   3.2347040E-03
         45   5.2000000E-03
         46   1.8465741E-02
         47   1.2066186E-02
         90   7.6999995E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6075917E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.6999995E-03
        147   9.1416575E-03
        148   4.6073981E-03
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
   TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

           6   0.0000000E+00   0.0000000E+00
          27   0.0000000E+00   0.0000000E+00
          28   0.0000000E+00   0.0000000E+00
          29   0.0000000E+00   0.0000000E+00
          45   0.0000000E+00   0.0000000E+00
          46   0.0000000E+00   0.0000000E+00
          47   0.0000000E+00   0.0000000E+00
          90   0.0000000E+00   0.0000000E+00
          93   0.0000000E+00   0.0000000E+00
         103   0.0000000E+00   0.0000000E+00
         122   0.0000000E+00   0.0000000E+00
         126   0.0000000E+00   4.5040000E-04
         127   0.0000000E+00   4.5040000E-04
         142   0.0000000E+00   4.5040000E-04
         144   0.0000000E+00   4.5040000E-04
         146   0.0000000E+00   4.5040000E-04
         147   0.0000000E+00   4.5040000E-04
         148   0.0000000E+00   4.5040000E-04
         162   0.0000000E+00   4.5040000E-04

 FOR ELEMENT # =             41

 THE CANOPY DENSITY=
  0.3685605

 THE COMPUTED THROUGHFALL VALUES=

   TIME(hr)    THROUGHFALL (m/hr)

           6   0.0000000E+00
          27   2.6000005E-03
          28   3.0106027E-04
          29   3.8224615E-03
          45   5.2000000E-03
          46   1.9059317E-02
          47   1.3841095E-02
          90   7.7000004E-03
          93   0.0000000E+00
         103   1.0000006E-04
         122   0.0000000E+00
         126   0.0000000E+00
         127   1.6221400E-02
         142   0.0000000E+00
         144   0.0000000E+00
         146   7.7000004E-03
         147   9.8807197E-03
         148   5.9400364E-03
         162   0.0000000E+00

 THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   0.0000000E+00
         93   0.0000000E+00   0.0000000E+00
        103   0.0000000E+00   0.0000000E+00
        122   0.0000000E+00   0.0000000E+00
        126   0.0000000E+00   3.5346402E-03
        127   0.0000000E+00   3.5346402E-03
        142   0.0000000E+00   3.5346402E-03
        144   0.0000000E+00   3.5346402E-03
        146   0.0000000E+00   3.5346402E-03
        147   0.0000000E+00   3.5346402E-03
        148   0.0000000E+00   3.5346402E-03
        162   0.0000000E+00   3.5346402E-03

FOR ELEMENT # =          42

THE CANOPY DENSITY=
 0.3103667

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   0.0000000E+00
         29   3.2347040E-03
         45   5.2000000E-03
         46   1.8465741E-02
         47   1.2066186E-02
         90   7.6999995E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6075917E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.6999995E-03
        147   9.1416575E-03
        148   4.6073981E-03
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   0.0000000E+00
         93   0.0000000E+00   0.0000000E+00
        103   0.0000000E+00   0.0000000E+00
        122   0.0000000E+00   0.0000000E+00
        126   0.0000000E+00   4.5040000E-04
        127   0.0000000E+00   4.5040000E-04
        142   0.0000000E+00   4.5040000E-04
        144   0.0000000E+00   4.5040000E-04
        146   0.0000000E+00   4.5040000E-04
        147   0.0000000E+00   4.5040000E-04
        148   0.0000000E+00   4.5040000E-04
        162   0.0000000E+00   4.5040000E-04

FOR ELEMENT # =            43

THE CANOPY DENSITY=
 0.4212120

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   7.0121151E-04
         29   4.3542413E-03
         45   5.1999995E-03
         46   1.9596362E-02
         47   1.5446967E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6353030E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.0549393E-02
        148   7.1457550E-03
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6   0.0000000E+00  0.0000000E+00
         27   0.0000000E+00  0.0000000E+00
         28   0.0000000E+00  0.0000000E+00
         29   0.0000000E+00  0.0000000E+00
         45   0.0000000E+00  0.0000000E+00
         46   0.0000000E+00  0.0000000E+00
         47   0.0000000E+00  0.0000000E+00
         90   0.0000000E+00  0.0000000E+00
         93   0.0000000E+00  0.0000000E+00
        103   0.0000000E+00  0.0000000E+00
        122   0.0000000E+00  0.0000000E+00
        126   0.0000000E+00  3.3409562E-04
        127   0.0000000E+00  3.3409562E-04
        142   0.0000000E+00  3.3409562E-04
        144   0.0000000E+00  3.3409562E-04
        146   0.0000000E+00  3.3409562E-04
        147   0.0000000E+00  3.3409562E-04
        148   0.0000000E+00  3.3409562E-04
        162   1.6440146E-02  3.3409562E-04

FOR ELEMENT # =          44

THE CANOPY DENSITY=
 0.4212120

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   7.0121151E-04
         29   4.3542413E-03
         45   5.1999995E-03
         46   1.9596362E-02
         47   1.5446967E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6353030E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.0549393E-02
        148   7.1457550E-03
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (HR)    EXCESS(m/hr)   INFILT(m/hr)

          6   0.0000000E+00  0.0000000E+00
         27   0.0000000E+00  0.0000000E+00
         28   0.0000000E+00  0.0000000E+00
         29   0.0000000E+00  0.0000000E+00
         45   0.0000000E+00  0.0000000E+00
         46   0.0000000E+00  0.0000000E+00
         47   0.0000000E+00  0.0000000E+00
         90   0.0000000E+00  0.0000000E+00
         93   0.0000000E+00  0.0000000E+00
        103   0.0000000E+00  0.0000000E+00
        122   0.0000000E+00  0.0000000E+00
        126   0.0000000E+00  0.0000000E+00
        127   0.0000000E+00  0.0000000E+00
        142   0.0000000E+00  0.0000000E+00
        144   0.0000000E+00  0.0000000E+00
        146   0.0000000E+00  0.0000000E+00
        147   0.0000000E+00  0.0000000E+00
        148   0.0000000E+00  0.0000000E+00
        162   0.0000000E+00  3.5346402E-03

FOR ELEMENT # =          45

THE CANOPY DENSITY=
 0.4212120

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  7.0121151E-04
         29  4.3542413E-03
         45  5.1999995E-03
         46  1.9596362E-02
         47  1.5446967E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6353030E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.0549393E-02
        148  7.1457550E-03
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   0.0000000E+00
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   0.0000000E+00
         93   0.0000000E+00   0.0000000E+00
        103   0.0000000E+00   0.0000000E+00
        122   0.0000000E+00   0.0000000E+00
        126   0.0000000E+00   0.0000000E+00
        127   0.0000000E+00   0.0000000E+00
        142   0.0000000E+00   0.0000000E+00
        144   0.0000000E+00   0.0000000E+00
        146   0.0000000E+00   0.0000000E+00
        147   0.0000000E+00   0.0000000E+00
        148   0.0000000E+00   0.0000000E+00
        162   0.0000000E+00   7.0414501E-03

FOR ELEMENT # =           46

THE CANOPY DENSITY=
 0.4212120

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   7.0121151E-04
         29   4.3542413E-03
         45   5.1999995E-03
         46   1.9596362E-02
         47   1.5446967E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6353030E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.0549393E-02
        148   7.1457550E-03
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
 TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

        6  0.0000000E+00  0.0000000E+00
       27  0.0000000E+00  0.0000000E+00
       28  0.0000000E+00  0.0000000E+00
       29  0.0000000E+00  0.0000000E+00
       45  0.0000000E+00  0.0000000E+00
       46  0.0000000E+00  0.0000000E+00
       47  0.0000000E+00  0.0000000E+00
       90  0.0000000E+00  0.0000000E+00
       93  0.0000000E+00  0.0000000E+00
      103  0.0000000E+00  0.0000000E+00
      122  0.0000000E+00  9.9999830E-05
      126  0.0000000E+00  0.0000000E+00
      127  0.0000000E+00  0.0000000E+00
      142  0.0000000E+00  0.0000000E+00
      144  0.0000000E+00  0.0000000E+00
      146  0.0000000E+00  0.0000000E+00
      147  0.0000000E+00  0.0000000E+00
      148  0.0000000E+00  0.0000000E+00
      162  0.0000000E+00  3.5346402E-03

FOR ELEMENT # =          47

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

 TIME(hr)   THROUGHFALL (m/hr)

        6  0.0000000E+00
       27  2.6000002E-03
       28  1.9816963E-03
       29  6.0559385E-03
       45  5.1999995E-03
       46  2.1314906E-02
       47  2.0585753E-02
       90  7.7000000E-03
       93  0.0000000E+00
      103  9.9999830E-05
      122  0.0000000E+00
      126  0.0000000E+00
      127  1.6774241E-02
      142  0.0000000E+00
      144  0.0000000E+00
      146  7.7000000E-03
      147  1.2689150E-02
      148  1.1004057E-02
      162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  0.0000000E+00  0.0000000E+00
         46  0.0000000E+00  0.0000000E+00
         47  0.0000000E+00  0.0000000E+00
         90  0.0000000E+00  0.0000000E+00
         93  0.0000000E+00  0.0000000E+00
        103  0.0000000E+00  0.0000000E+00
        122  0.0000000E+00  0.0000000E+00
        126  0.0000000E+00  0.0000000E+00
        127  0.0000000E+00  0.0000000E+00
        142  0.0000000E+00  0.0000000E+00
        144  0.0000000E+00  0.0000000E+00
        146  0.0000000E+00  0.0000000E+00
        147  0.0000000E+00  0.0000000E+00
        148  1.3239601E-02  3.5346402E-03
        162  0.0000000E+00  3.5346402E-03

FOR ELEMENT # =           48

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
   TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

           6  0.0000000E+00  0.0000000E+00
          27  0.0000000E+00  0.0000000E+00
          28  0.0000000E+00  0.0000000E+00
          29  0.0000000E+00  0.0000000E+00
          45  0.0000000E+00  0.0000000E+00
          46  0.0000000E+00  0.0000000E+00
          47  0.0000000E+00  0.0000000E+00
          90  0.0000000E+00  0.0000000E+00
          93  0.0000000E+00  0.0000000E+00
         103  0.0000000E+00  0.0000000E+00
         122  0.0000000E+00  0.0000000E+00
         126  0.0000000E+00  0.0000000E+00
         127  0.0000000E+00  0.0000000E+00
         142  0.0000000E+00  0.0000000E+00
         144  0.0000000E+00  0.0000000E+00
         146  0.0000000E+00  0.0000000E+00
         147  0.0000000E+00  0.0000000E+00
         148  0.0000000E+00  3.5346402E-03
         162  0.0000000E+00  3.5346402E-03

 FOR ELEMENT # =           49

 THE CANOPY DENSITY=
  0.5896968

 THE COMPUTED THROUGHFALL VALUES=

   TIME(hr)   THROUGHFALL (m/hr)

           6  0.0000000E+00
          27  2.6000002E-03
          28  1.9816963E-03
          29  6.0559385E-03
          45  5.1999995E-03
          46  2.1314906E-02
          47  2.0585753E-02
          90  7.7000000E-03
          93  0.0000000E+00
         103  9.9999830E-05
         122  0.0000000E+00
         126  0.0000000E+00
         127  1.6774241E-02
         142  0.0000000E+00
         144  0.0000000E+00
         146  7.7000000E-03
         147  1.2689150E-02
         148  1.1004057E-02
         162  0.0000000E+00

 THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  0.0000000E+00
         45  0.0000000E+00  0.0000000E+00
         46  0.0000000E+00  0.0000000E+00
         47  0.0000000E+00  0.0000000E+00
         90  0.0000000E+00  0.0000000E+00
         93  0.0000000E+00  0.0000000E+00
        103  0.0000000E+00  0.0000000E+00
        122  0.0000000E+00  0.0000000E+00
        126  0.0000000E+00  0.0000000E+00
        127  0.0000000E+00  0.0000000E+00
        142  1.2818390E-02  3.5346402E-03
        144  0.0000000E+00  3.5346402E-03
        146  0.0000000E+00  3.5346402E-03
        147  0.0000000E+00  3.5346402E-03
        148  0.0000000E+00  3.5346402E-03
        162  0.0000000E+00  3.5346402E-03

FOR ELEMENT # =          50

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  0.0000000E+00
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  2.6000002E-03
         45  0.0000000E+00  0.0000000E+00
         46  0.0000000E+00  0.0000000E+00
         47  0.0000000E+00  0.0000000E+00
         90  0.0000000E+00  0.0000000E+00
         93  0.0000000E+00  0.0000000E+00
        103  0.0000000E+00  0.0000000E+00
        122  0.0000000E+00  0.0000000E+00
        126  0.0000000E+00  0.0000000E+00
        127  0.0000000E+00  0.0000000E+00
        142  0.0000000E+00  3.5346402E-03
        144  0.0000000E+00  3.5346402E-03
        146  0.0000000E+00  3.5346402E-03
        147  0.0000000E+00  3.5346402E-03
        148  0.0000000E+00  3.5346402E-03
        162  7.4694166E-03  3.5346402E-03

FOR ELEMENT # =          51

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)    THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6   0.0000000E+00   0.0000000E+00
         27   0.0000000E+00   0.0000000E+00
         28   0.0000000E+00   0.0000000E+00
         29   0.0000000E+00   2.6000002E-03
         45   0.0000000E+00   0.0000000E+00
         46   0.0000000E+00   0.0000000E+00
         47   0.0000000E+00   0.0000000E+00
         90   0.0000000E+00   0.0000000E+00
         93   0.0000000E+00   0.0000000E+00
        103   0.0000000E+00   0.0000000E+00
        122   0.0000000E+00   0.0000000E+00
        126   0.0000000E+00   0.0000000E+00
        127   0.0000000E+00   0.0000000E+00
        142   0.0000000E+00   0.0000000E+00
        144   0.0000000E+00   0.0000000E+00
        146   0.0000000E+00   0.0000000E+00
        147   0.0000000E+00   0.0000000E+00
        148   0.0000000E+00   0.0000000E+00
        162   0.0000000E+00   3.5346402E-03

FOR ELEMENT # =           52

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6   0.0000000E+00
         27   2.6000002E-03
         28   1.9816963E-03
         29   6.0559385E-03
         45   5.1999995E-03
         46   2.1314906E-02
         47   2.0585753E-02
         90   7.7000000E-03
         93   0.0000000E+00
        103   9.9999830E-05
        122   0.0000000E+00
        126   0.0000000E+00
        127   1.6774241E-02
        142   0.0000000E+00
        144   0.0000000E+00
        146   7.7000000E-03
        147   1.2689150E-02
        148   1.1004057E-02
        162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
 TIME (hr)    EXCESS(m/hr)   INFILT(m/hr)

         6   0.0000000E+00  0.0000000E+00
        27   0.0000000E+00  0.0000000E+00
        28   0.0000000E+00  2.6000002E-03
        29   0.0000000E+00  1.3629184E-04
        45   0.0000000E+00  0.0000000E+00
        46   0.0000000E+00  0.0000000E+00
        47   1.6653594E-03  3.5346402E-03
        90   0.0000000E+00  3.5346402E-03
        93   0.0000000E+00  3.5346402E-03
       103   0.0000000E+00  3.5346402E-03
       122   0.0000000E+00  3.5346402E-03
       126   0.0000000E+00  3.5346402E-03
       127   0.0000000E+00  3.5346402E-03
       142   0.0000000E+00  3.5346402E-03
       144   0.0000000E+00  3.5346402E-03
       146   0.0000000E+00  3.5346402E-03
       147   0.0000000E+00  3.5346402E-03
       148   0.0000000E+00  3.5346402E-03
       162   0.0000000E+00  3.5346402E-03

FOR ELEMENT # =           53

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

 TIME(hr)    THROUGHFALL (m/hr)

         6   0.0000000E+00
        27   2.6000002E-03
        28   1.9816963E-03
        29   6.0559385E-03
        45   5.1999995E-03
        46   2.1314906E-02
        47   2.0585753E-02
        90   7.7000000E-03
        93   0.0000000E+00
       103   9.9999830E-05
       122   0.0000000E+00
       126   0.0000000E+00
       127   1.6774241E-02
       142   0.0000000E+00
       144   0.0000000E+00
       146   7.7000000E-03
       147   1.2689150E-02
       148   1.1004057E-02
       162   0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  2.6000002E-03
         28  0.0000000E+00  0.0000000E+00
         29  0.0000000E+00  1.9816963E-03
         45  0.0000000E+00  0.0000000E+00
         46  1.6653594E-03  3.5346402E-03
         47  1.7780267E-02  3.5346402E-03
         90  0.0000000E+00  3.5346402E-03
         93  4.1653598E-03  3.5346402E-03
        103  0.0000000E+00  3.5346402E-03
        122  0.0000000E+00  3.5346402E-03
        126  0.0000000E+00  3.5346402E-03
        127  0.0000000E+00  3.5346402E-03
        142  0.0000000E+00  3.5346402E-03
        144  0.0000000E+00  3.5346402E-03
        146  0.0000000E+00  3.5346402E-03
        147  0.0000000E+00  3.5346402E-03
        148  0.0000000E+00  3.5346402E-03
        162  0.0000000E+00  3.5346402E-03

FOR ELEMENT # =           54

THE CANOPY DENSITY=
 0.4212120

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  7.0121151E-04
         29  4.3542413E-03
         45  5.1999995E-03
         46  1.9596362E-02
         47  1.5446967E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6353030E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.0549393E-02
        148  7.1457550E-03
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
  TIME (hr)   EXCESS(m/hr)   INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  2.6000002E-03
         28  0.0000000E+00  0.0000000E+00
         29  2.5212984E-03  3.5346402E-03
         45  1.6653598E-03  3.5346402E-03
         46  1.7780267E-02  3.5346402E-03
         47  1.1912327E-02  3.5346402E-03
         90  0.0000000E+00  3.5346402E-03
         93  0.0000000E+00  3.5346402E-03
        103  0.0000000E+00  3.5346402E-03
        122  0.0000000E+00  3.5346402E-03
        126  0.0000000E+00  3.5346402E-03
        127  0.0000000E+00  3.5346402E-03
        142  0.0000000E+00  3.5346402E-03
        144  0.0000000E+00  3.5346402E-03
        146  0.0000000E+00  0.0000000E+00
        147  0.0000000E+00  0.0000000E+00
        148  4.1653598E-03  3.5346402E-03
        162  0.0000000E+00  3.5346402E-03

FOR ELEMENT # =          55

THE CANOPY DENSITY=
 0.5896968

THE COMPUTED THROUGHFALL VALUES=

  TIME(hr)   THROUGHFALL (m/hr)

          6  0.0000000E+00
         27  2.6000002E-03
         28  1.9816963E-03
         29  6.0559385E-03
         45  5.1999995E-03
         46  2.1314906E-02
         47  2.0585753E-02
         90  7.7000000E-03
         93  0.0000000E+00
        103  9.9999830E-05
        122  0.0000000E+00
        126  0.0000000E+00
        127  1.6774241E-02
        142  0.0000000E+00
        144  0.0000000E+00
        146  7.7000000E-03
        147  1.2689150E-02
        148  1.1004057E-02
        162  0.0000000E+00

THE COMPUTED INFILTRATION VALUES=
 TIME (hr)    EXCESS(m/hr)    INFILT(m/hr)

          6  0.0000000E+00  0.0000000E+00
         27  0.0000000E+00  2.6000002E-03
         28  0.0000000E+00  1.9816963E-03
         29  2.5212984E-03  3.5346402E-03
         45  1.6653594E-03  3.5346402E-03
         46  1.7780267E-02  3.5346402E-03
         47  1.7051114E-02  3.5346402E-03
         90  4.1653598E-03  3.5346402E-03
         93  0.0000000E+00  3.5346402E-03
        103  0.0000000E+00  3.5346402E-03
        122  0.0000000E+00  3.5346402E-03
        126  0.0000000E+00  0.0000000E+00
        127  1.3239601E-02  3.5346402E-03
        142  0.0000000E+00  3.5346402E-03
        144  0.0000000E+00  3.5346402E-03
        146  4.1653598E-03  3.5346402E-03
        147  9.1545098E-03  3.5346402E-03
        148  7.4694166E-03  3.5346402E-03
        162  0.0000000E+00  3.5346402E-03
```

```
CHANNEL FLOW INPUT DATA

  RLEN    HTOTC   XX      SLOP

          UNITS:

   m        m

1200.00  250.00 0.25 0.150000
2400.00   90.00 0.25 0.025000
1800.00  300.00 0.25 0.150000
1400.00  300.00 0.25 0.180000
1500.00  100.00 0.25 0.067000
1300.00  100.00 0.25 0.077000
1600.00   90.00 0.25 0.069000
1260.00   15.00 0.25 0.024000
1000.00   40.00 0.25 0.050000
1400.00   40.00 0.25 0.036000
1600.00  250.00 0.25 0.031000
1500.00   30.00 0.25 0.007000
2400.00  100.00 0.25 0.063000
1300.00  100.00 0.25 0.008000
1500.00  100.00 0.25 0.007000
```

```
1200.00    85.00 0.25 0.008000
1200.00    85.00 0.25 0.008000
1000.00    80.00 0.25 0.010000
1200.00    80.00 0.25 0.008000
1200.00    70.00 0.25 0.017000
1200.00    50.00 0.25 0.008000
1000.00    50.00 0.25 0.040000
1000.00    40.00 0.25 0.010000
1200.00    25.00 0.25 0.013000
1000.00    22.00 0.25 0.003000
1100.00    22.00 0.25 0.009000
1200.00    15.00 0.25 0.004000
1600.00     9.00 0.25 0.004000
1000.00     9.00 0.25 0.006000
1200.00     4.00 0.25 0.004000
1200.00     1.00 0.25 0.003000
1400.00     0.50 0.25 0.001000


DATA FOR REGRESSION ANALYSIS

THE NUMBER OF REGRESSION DATA POINTS=?             20

QQR = DISCHARGES(m/s) SURF= AREAS(km2)
   QQR            SURF

  3.540000        42.50000
 0.2268000        2.620000
 4.6999999E-03   0.1700000
 0.6300000        22.33000
  1.093800        38.60000
  14.72670        520.0000
  4.049800        143.0000
  15.26480        539.0000
  8.807700        311.0000
  2.670600        94.30000
  4.729500        47.70000
  10.50690        149.5200
  4.531300        142.0000
 0.5466000        8.420000
 0.5126000        9.690000
 0.5353000        26.40000
  1.353700        20.44000
  16.00110        233.0000
  2.010000        71.20000
  4.446300        39.00000
    GAMMA       LAMBDA
 1.00000000  0.00000000

      YY0           VM      WLVEL       CBOTTOM
      m             m/s        m          m

   0.8647        0.0403    249.4790   248.6143
   0.8647        0.0403     89.4790    88.6143
   0.8647        0.0403    299.4789   298.6143
   0.8647        0.0403    299.4789   298.6143
   0.8647        0.0403     99.4790    98.6143
   0.8647        0.0403     99.4790    98.6143
   1.1307        0.0527     89.4124    88.2817
   0.8647        0.0403     14.4790    13.6143
   0.8647        0.0403     39.4790    38.6143
   0.8647        0.0403     39.4790    38.6143
   0.8647        0.0403    249.4790   248.6143
   0.8647        0.0403     29.4790    28.6143
   0.8647        0.0403     99.4790    98.6143
   0.8647        0.0403     99.4790    98.6143
   0.8647        0.0403     99.4790    98.6143
   0.7202        0.0336     84.5151    83.7949
   0.8647        0.0403     84.4790    83.6143
   1.1307        0.0527     79.4124    78.2817
   1.1307        0.0527     79.4124    78.2817
   0.7202        0.0336     69.5151    68.7949
   0.7202        0.0336     49.5151    48.7949
   0.7202        0.0336     49.5151    48.7949
   0.7202        0.0336     39.5151    38.7949
   0.7202        0.0336     24.5151    23.7949
   0.7202        0.0336     21.5151    20.7949
   0.7202        0.0336     21.5151    20.7949
   0.7202        0.0336     14.5151    13.7949
   0.7202        0.0336      8.5151     7.7949
   0.7202        0.0336      8.5151     7.7949
   0.7202        0.0336      3.5151     2.7949
   0.7202        0.0336      0.5151     0.0000
   0.7202        0.0336      0.0151     0.0000
```

```
OVERLAND FLOW INPUT DATA

 WHYO      AA       SLPE    ALPHA3

         UNITS:

  m        m               DEGREES

0.0000  1000.00 0.100000  270.0
0.0000  1000.00 0.250000  270.0
0.0000  1000.00 0.150000  270.0
0.0000  1200.00 0.110000    0.0
0.0000  1000.00 0.100000  180.0
```

```
0.0000  1000.00 0.050000    0.0
0.0000  1200.00 0.125000  180.0
0.0000  1200.00 0.042000    0.0
0.0000  1000.00 0.050000    0.0
0.0000  1600.00 0.023000    0.0
0.0000  1200.00 0.036000   45.0
0.0000  1400.00 0.176000  180.0
0.0000   700.00 0.143000  180.0
0.0000  1000.00 0.050000    0.0
0.0000  1000.00 0.100000  180.0
0.0000  1000.00 0.083000  180.0
0.0000  1000.00 0.050000    0.0
0.0000  1000.00 0.133000  180.0
0.0000  1000.00 0.070000    0.0
0.0000  1000.00 0.250000  180.0
0.0000  1100.00 0.064000    0.0
0.0000   900.00 0.050000  180.0
0.0000  1320.00 0.030000    0.0
0.0000  1000.00 0.041000    0.0
0.0000  1000.00 0.045000    0.0
0.0000  1000.00 0.250000  270.0
0.0000  1600.00 0.156000    0.0
0.0000  1200.00 0.125000    0.0
0.0000  1200.00 0.035000    0.0
0.0000  1400.00 0.080000  240.0
0.0000   700.00 0.086000  180.0
0.0000  1000.00 0.050000  270.0
0.0000  1000.00 0.020000  180.0
0.0000  1000.00 0.014000    0.0
0.0000   900.00 0.017000  225.0
0.0000  1000.00 0.005000    0.0
0.0000  1000.00 0.286000  225.0
0.0000  1300.00 0.070000    0.0
0.0000  1400.00 0.286000  270.0
0.0000  1400.00 0.107000    0.0
0.0000  1300.00 0.033000    0.0
0.0000  1400.00 0.050000    0.0
0.0000  1200.00 0.042000    0.0
0.0000  1200.00 0.031000    0.0
0.0000  1200.00 0.020000    0.0
0.0000  1200.00 0.020000    0.0
0.0000  1000.00 0.010000    0.0
0.0000  1000.00 0.020000    0.0
0.0000  1000.00 0.020000    0.0
0.0000  1000.00 0.010000    0.0
0.0000  1000.00 0.010000    0.0
0.0000  1000.00 0.010000    0.0
0.0000  1000.00 0.005000    0.0
0.0000  1200.00 0.002000    0.0
0.0000  1000.00 0.001000    0.0
```

GROUNDWATER FLOW INPUT DATA

PCO	HCO	WIC	FC	COEFF	RMAXZD	DMAX
			UNITS:			
					m	m
2.0000	8.0000	0.0330	0.1110	0.001	1.75	3.00
2.0000	8.0000	0.0330	0.1110	0.001	1.75	3.00
2.0000	8.0000	0.0330	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
40.0000	24.0000	0.0370	0.1230	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
40.0000	24.0000	0.0370	0.1230	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
40.0000	24.0000	0.0610	0.1230	0.001	1.75	3.00
40.0000	24.0000	0.0370	0.1230	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
40.0000	24.0000	0.0370	0.1230	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00
47.0000	20.0000	0.0610	0.1110	0.001	1.75	3.00
40.0000	24.0000	0.0370	0.1230	0.001	1.75	3.00
30.0000	9.0000	0.0340	0.1160	0.001	1.75	3.00

```
20.0000 19.0000 0.0340 0.1140      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00
30.0000  9.0000 0.0340 0.1160      0.001  1.75  3.00

DISCHARGE QOUTOT (m3/s)

  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  1.7556
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  1.7314
  3.3609
  4.0297
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
  0.0000
```

```
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
1.7313
3.3611
4.0309
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
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0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
```

```
0.0000
1.7313
0.0000
0.0000
1.7314
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
1.7314
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
1.7318
0.0000
0.0000
0.0000
1.7552
3.3830
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
0.0000
```

```
      0.0000
      1.7314
      0.0000
      1.7314
      0.0000
      1.7313
      3.3616
      4.0267
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000
      1.7314
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000
      0.0000

   TIME       DISCHARGE Q
   (hr)       (m3/s)

       1    0.0000 I

       2    0.0000 I

       3    0.0000 I

       4    0.0000 I

       5    0.0000 I

       6    1.7556 I   *

       7    0.0000 I

       8    0.0000 I

       9    0.0000 I

      10    0.0000 I
```

```
11   0.0000 I
12   0.0000 I
13   0.0000 I
14   0.0000 I
15   0.0000 I
16   0.0000 I
17   0.0000 I
18   0.0000 I
19   0.0000 I
20   0.0000 I
21   0.0000 I
22   0.0000 I
23   0.0000 I
24   0.0000 I
25   0.0000 I
26   0.0000 I
27   1.7314 I  *
28   3.3609 I   *
29   4.0297 I    *
30   0.0000 I
31   0.0000 I
32   0.0000 I
33   0.0000 I
34   0.0000 I
35   0.0000 I
36   0.0000 I
```

```
37   0.0000 I
38   0.0000 I
39   0.0000 I
40   0.0000 I
41   0.0000 I
42   0.0000 I
43   0.0000 I
44   0.0000 I
45   1.7313 I  *
46   3.3611 I   *
47   4.0309 I    *
48   0.0000 I
49   0.0000 I
50   0.0000 I
51   0.0000 I
52   0.0000 I
53   0.0000 I
54   0.0000 I
55   0.0000 I
56   0.0000 I
57   0.0000 I
58   0.0000 I
59   0.0000 I
60   0.0000 I
61   0.0000 I
62   0.0000 I
```

```
63   0.0000 I
64   0.0000 I
65   0.0000 I
66   0.0000 I
67   0.0000 I
68   0.0000 I
69   0.0000 I
70   0.0000 I
71   0.0000 I
72   0.0000 I
73   0.0000 I
74   0.0000 I
75   0.0000 I
76   0.0000 I
77   0.0000 I
78   0.0000 I
79   0.0000 I
80   0.0000 I
81   0.0000 I
82   0.0000 I
83   0.0000 I
84   0.0000 I
85   0.0000 I
86   0.0000 I
87   0.0000 I
88   0.0000 I
```

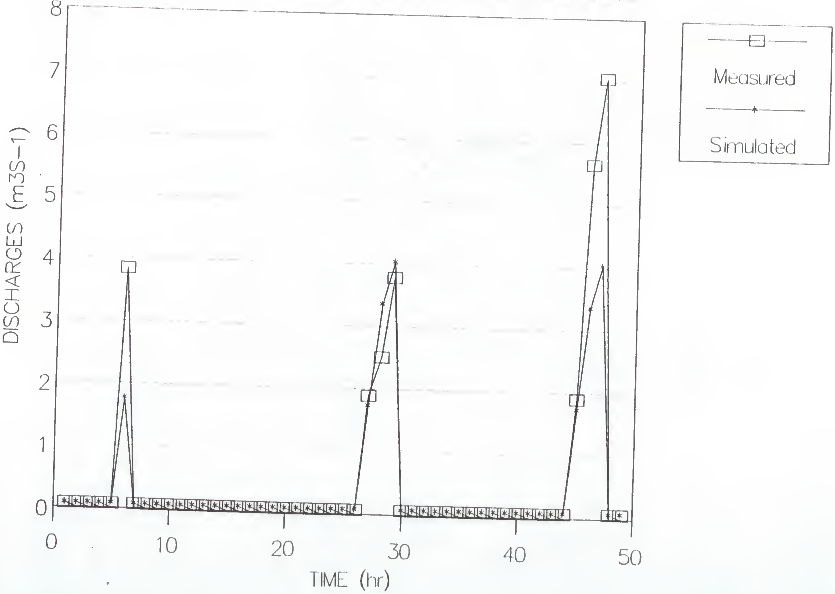
```
 89   0.0000 I
 90   1.7313 I  *
 91   0.0000 I
 92   0.0000 I
 93   1.7314 I  *
 94   0.0000 I
 95   0.0000 I
 96   0.0000 I
 97   0.0000 I
 98   0.0000 I
 99   0.0000 I
100   0.0000 I
101   0.0000 I
102   0.0000 I
103   1.7314 I  *
104   0.0000 I
105   0.0000 I
106   0.0000 I
107   0.0000 I
108   0.0000 I
109   0.0000 I
110   0.0000 I
111   0.0000 I
112   0.0000 I
113   0.0000 I
114   0.0000 I
```

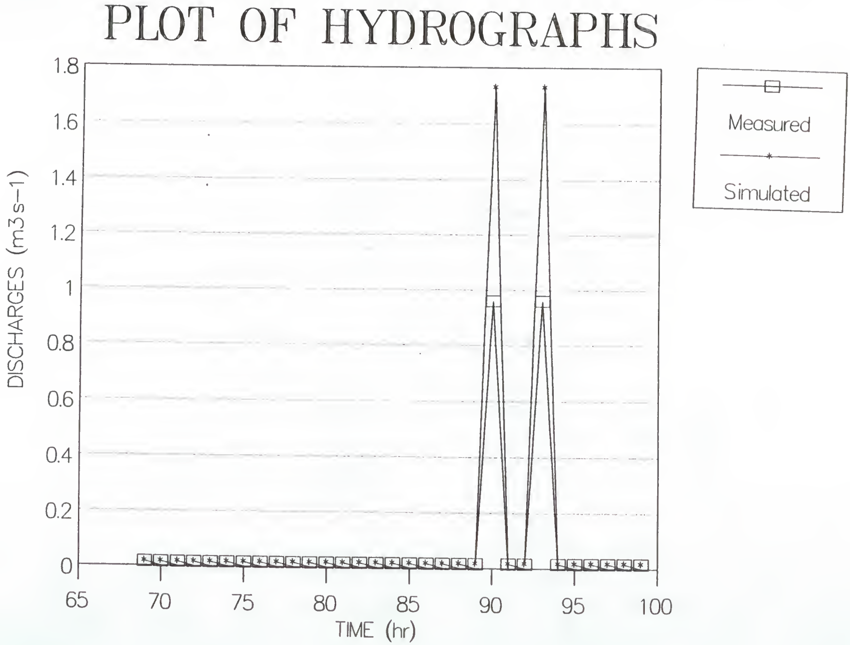
```
115   0.0000 I

116   0.0000 I

117   0.0000 I

118   0.0000 I

119   0.0000 I

120   0.0000 I

121   0.0000 I

122   1.7318 I  *

123   0.0000 I

124   0.0000 I

125   0.0000 I

126   1.7552 I  *

127   3.3830 I   *

128   0.0000 I

129   0.0000 I

130   0.0000 I

131   0.0000 I

132   0.0000 I

133   0.0000 I

134   0.0000 I

135   0.0000 I

136   0.0000 I

137   0.0000 I

138   0.0000 I

139   0.0000 I

140   0.0000 I
```

```
141   0.0000 I
142   1.7314 I  *
143   0.0000 I
144   1.7314 I  *
145   0.0000 I
146   1.7313 I  *
147   3.3616 I   *
148   4.0267 I    *
149   0.0000 I
150   0.0000 I
151   0.0000 I
152   0.0000 I
153   0.0000 I
154   0.0000 I
155   0.0000 I
156   0.0000 I
157   0.0000 I
158   0.0000 I
159   0.0000 I
160   0.0000 I
161   0.0000 I
162   1.7314 I  *
163   0.0000 I
164   0.0000 I
165   0.0000 I
166   0.0000 I
```

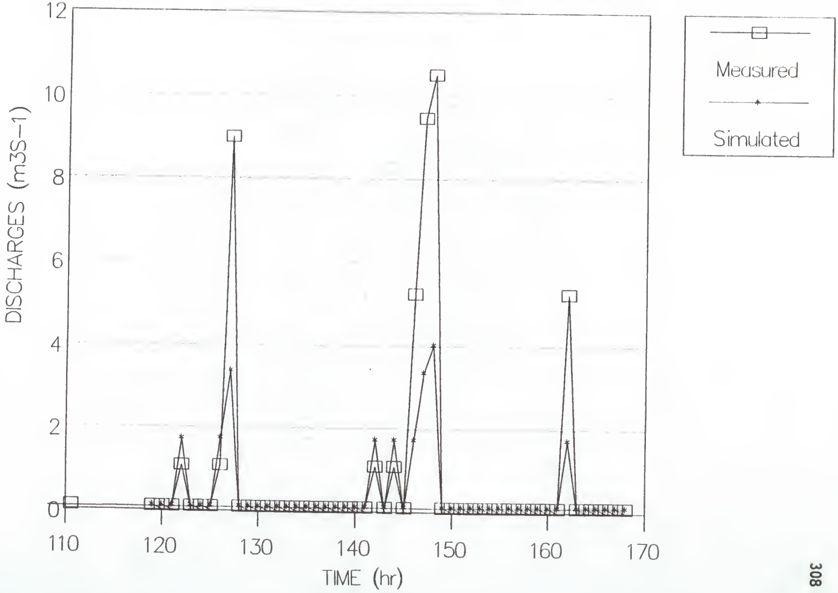
```
 167   0.0000 I

 168   0.0000 I

THIS IS THE VALUE OF THE CORRELATION COEF- FICIENT RSQ
 0.9450524
THE FLOW VALUES OBTAINED ARE GOOD NO FURTHER CALIBRATION IS
NECESSARY
```

PLOT OF HYDROGRAPHS




PLOT OF HYDROGRAPHS
DISCHARGES (m3 s−1)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
65
70
75
80
85
90
95
100
TIME (hr)
Measured
Simulated

PLOT OF HYDROGRAPHS



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BIOGRAPHICAL SKETCH

Koné Siaka was born in Aboisso, Cote d'Ivoires, son of Vamara Koné and N'Guessan Amoin. He attended primary school in his hometown in Aboisso and graduated in 1969. He completed the first section of high school with the Diploma B.E.P.C. in 1973 and the second section in 1976, with the diploma 'baccaleaut C' (mathematics and physics) with honors. He then entered the E.N.S.T.P. (Ecole Nationale Superieure des Travaux Publics). He obtained the degree Diplome d'Ingenieur de Genie Civil from the E.N.S.T.P. in 1983. He worked as a consulting civil engineer for a few months in the state corporation called "Direction Centrale de l'Hydraulique," then received a scholarship to study in the United States. He enrolled at the University of Florida and received a Master of Engineering in agricultural engineering in 1988. Koné is now a research assistant at the Department of Civil Engineering at the University of Florida where he expects to finish his Ph.D. work in May 1991. In July, 1987, he married Walemin Emilienne of Aboisso, his hometown. They have a two-year-old little girl Ferima. Koné is a born again Christian, believer in Jesus Christ.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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